ERGONOMICS

HUMAN FACTORS IN WORK, MACHINE CONTROL AND EQUIPMENT DESIGN

A Taylor and Francis International Journal

The Official Publication of the Ergonomics Research Society

Volume 2 **Number 2**

February 1959

ALERE FLAMMAM.

Printed and Published by

TAYLOR & FRANCIS LTD.

RED LION COURT, FLEET STREET, LONDON, E.C.4

ERGONOMICS

Human Factors in Work, Machine Control and Equipment Design

Price £1 5s. 0d. per part

Subscription price per volume £4 15s. 0d. post free, payable in advance

Agents for U.S.A. and Canada

Academic Press Inc., 111 Fifth Avenue, New York 3, N.Y., U.S.A.

$3.50 per part. $13.30 per volume.

INTERNATIONAL JOURNAL OF

RADIATION BIOLOGY

and related studies in Physics, Chemistry and Medicine

Editor

W. M. DALE, M.D., D.SC.

Dept. of Biochemistry, Christie Hospital & Holt Radium Institute, Withington, Manchester, 20

Assistant Editor

JOHN WAKEFIELD, B.A., F.Z.S.

Contents of January, 1959

Price per part £1 0s. 0d. plus postage

Subscription per volume (4 issues) £3 15s. 0d. post free, payable in advance

Printed and Published by

TAYLOR & FRANCIS LTD

RED LION COURT, FLEET STREET, LONDON, E.C.4

Orders originating in U.S.A. and Canada should be sent to the Academic Press Inc., 111 Fifth Avenue, New York 3, N.Y., U.S.A.

Journal of Electronics and Control

A Philosophical Magazine Associated Journal

Contents of January, 1959

Electronics Section

Control Section

Price per part £1 5s. plus postage
Price per volume £7 post free, payable in advance
6 monthly issues per volume

Printed and Published by

TAYLOR & FRANCIS LTD
RED LION COURT, FLEET STREET, LONDON, E.C.4

Orders originating in U.S.A. and Canada should be sent to the Academic Press Inc., 111 Fifth Avenue, New York, 3, N.Y., U.S.A.

Physics in Medicine and Biology

A Taylor & Francis Journal published in association with The Hospital Physicists' Association

Contents of January, 1959

Subscription price per volume £3 10s. post free, payable in advance

4 parts per volume—£1 per part plus postage

Printed and Published by

TAYLOR & FRANCIS, LTD

RED LION COURT, FLEET STREET, LONDON, E.C.4

Orders originating in U.S.A. and Canada should be sent to the Academic Press Inc., 111 Fifth Avenue, New York, 3, N.Y., U.S.A.

The Philosophical Magazine

First Published in 1798

Contents of February, 1959

Price per part £1 5s. plus postage
Price per annum £13 10s. post free, payable in advance

Printed and Published by

TAYLOR & FRANCIS LTD

RED LION COURT, FLEET STREET, LONDON, E.C.4

Advances in Physics

A Quarterly Supplement of the Philosophical Magazine

Contents of January, 1959

Price per part £1 plus postage

Price per annum £3 15s. post free

Printed and Published by

TAYLOR & FRANCIS LTD

RED LION COURT, FLEET STREET, LONDON, E.C.4

INTERNATIONAL JOURNAL

OPTICA ACTA

European Journal of Optics | **Journal Européen d'Optique** | **Europäische Zeitschrift für Optik**

English Editor: C. G. WYNNE, 13 Elwill Way, Beckenham, Kent, U.K.

Rédacteur Français: A. MARÉCHAL, 3 Boulevard Pasteur, Paris, France

Deutscher Herausgeber: G. FRANKE, Laufdorfer Weg 2, Wetzlar, Germany

Contents of January, 1959

Price per part £1 (1375 fr.), (DM 11.75), ($2.80), plus postage

Subscription price per volume (4 parts) £3 15s. (5155 fr.), (DM 44), ($10.50), post free, payable in advance

Printed and Published by

TAYLOR & FRANCIS LTD

RED LION COURT, FLEET STREET, LONDON, E.C.4

SYMPOSIUM ON TRAINING

The papers in this issue are all based on communications made at a *Symposium on Training* held by the Ergonomics Research Society at the University of Bristol Department of Engineering from 13 to 16 April 1958.

The training of industrial skills and physical training of the body are both considered, in the light of recent psychological and physiological studies.

INTRODUCTORY ADDRESS

By P. H. St. J. Wilson, C.B., C.B.E.

Chief Industrial Commissioner, Ministry of Labour and National Service

Current trends in the fields of apprentice, semi-skilled and unskilled, supervisory and management training are discussed. Higher management interest, the need to have clear objectives, the appointment of persons responsible for training, proper training facilities, and the integration and continuity of training programmes are then considered as essential factors in successful training. The question, ‘ Does training pay ? ’ is examined.

§ 1. Introduction

It is really rather an impertinence on my part to come here and talk to an audience of experts on the subject of training problems. I have no conscious recollection of having been trained for anything except as a galley slave for some years at school and at Cambridge. It is true that in the past I have had some responsibility for the training interests of the Ministry of Labour. For a number of years on and off I have been associated with the quite remarkable work done in our Government Training Centres and other training centres, and also our Industrial Rehabilitation Units, as well as with the Youth Employment work of our Department, which involves some knowledge of apprenticeship questions. I laboured in the field of supervisory training for a while and have spoken on that subject in various parts of the country; but, so far as I am concerned, training has been something which other people need, or at least something which other people get, for I have never had any hitherto, and the chances of my doing so are getting less and less as the years advance.

However, one does get around industry and other places quite a bit in the Ministry of Labour, and one ought to be able to get a sort of synoptic view of the problems of training. I propose to give you a brief review of industrial training in this country, indicating to the best of my knowledge the successes and failures, the gaps and deficiencies—there are no notable excesses, as far as I am aware. Following this, I will try to give some general views about the nature of training and its current needs.

§ 2. Training of Young Workers

Let me start at the lowest age-point, though I hasten to say that it is in fact the most crucial: the training of the young worker first entering industry. The Ministry of Labour has just published a report on the training of young people, the Carr Report (Ministry of Labour and National Service 1958). The

Carr Committee had a simple objective, to consider the adequacy, both in quantity and quality, of the training of young people for work, with particular reference to the impending entry into employment of the famous population ‘ bulge ’. This has hitherto been an educational problem but it is now passing into employment. The Committee did not intend just to produce a report. It had the intention of getting industry to think about the problem before the report emerged. It tried to do this by putting before every Joint Industrial Council and similar body in the country a questionnaire, and asking for a reply in the name of the National Joint Advisory Council of the Ministry of Labour. This is the top Joint Industrial Council of the country, so to speak, and the Carr Committee was technically a Sub-Committee of it.

It is not necessary to consider the details of the Committee's findings, but under the decent veil of official prose it commented pretty adversely both on the quantity and quality of apprenticeship training in the country as a whole. So far as quality is concerned, the Committee blessed the traditional system of apprenticeship training, still virtually the only way to skilled employment in this country, as the foundation for all skilled training. However, it suggested greater flexibility in length and variety, better selection methods, and better training methods, including better trained instructors. Its other suggestions were for better coordination between industrial training and Technical Colleges, better supervision of training programmes from the top of industry, and a National Advisory Council to encourage the whole thing from the centre. So far as quantity is concerned, the Committee appealed to industry to take advantage of the present unique opportunity of increasing its skilled labour force by greatly increasing its training programme for young people.

There are also recommendations about training which should be given to young people in non-apprenticeship employment, and about the better use of girl talent in craft apprenticeship and the like.

All this has been thrust upon industry, but I am happy to say that it is being taken seriously. In particular, the British Employers' Confederation has already set up a Conference to begin examination of the subject.

§ 3. Training Adult Workers

Going upward in the age-scale, we come to the question of the training of semi-skilled and unskilled workers. I am rather ashamed to say that the Ministry of Labour has not hitherto taken a lead on this subject. Some people think we should and we may well do something about it in the not too distant future. However, the gap has been very well filled by a survey by the National Institute of Industrial Psychology (1957) on training factory workers. It is not going too far to say that this was a rather disturbing report. It showed very little attempt on the part of British industry to get beyond the stage so well described in the U.S.A. as ‘sitting by Nellie’ in the training of non-skilled workers. Particularly, it picks upon the same point as the Carr Committee, the inadequate instruction given to people who themselves are to give training: no training at all in the case of one quarter of those surveyed; Training Within Industry Job Instruction in the case of just under one-half; and in the remaining third some special form of training at least equivalent to Job Instruction.

Perhaps I could just pause on this point, which has already arisen twice in this survey, and say that this is a need which we ourselves discovered some time

ago in our own programmes of training in Government Training Centres and Industrial Rehabilitation Units. For this highly important and difficult work we recruit men of the highest skill and knowledge in their craft. We have discovered the fairly obvious fact that though a man may have all the knowledge in his head, and skill in his fingers, he may often have not the least idea of how to convey it to others in instruction. So we set up our own Staff College at Letchworth, giving a highly practical three weeks' course in the technique of instruction. Then some friends from industry came to see what we were doing and said that this was just what they had been looking for for some time. So we put on a special course for apprentice masters, training officers and the like, with the result that this College is now booked up twelve months ahead, mostly with people from industry. It is clear that this course fills a demand, and judging by our 'fan mail', it is filling it very satisfactorily. If it is to go on like this we may have to expand our facilities.

It might perhaps be worth mentioning in parenthesis that for Technical College instructors the Education Ministries have a twelve-month part-time course, so even a very intensive fortnightly course such as we give is not excessive.

Before I move on to my next topics, let me just say a word about our own experience of training men for skilled occupations in our Government Training Centres. We have had forty years of this, with various types of people: ex-Servicemen after the 1914–18 war, unemployed men in the 'thirties, and now mainly disabled persons, or ex-Regulars needing resettlement in civil life. We have demonstrated quite conclusively that given reasonable material, a six months' intensive course can put a man as far along the road to a skilled occupation as two, three or even more years' apprenticeship of the old-fashioned, leisurely type. It is rather mortifying that, due mainly to Trade Union opposition, we have not been allowed to make greater use of this technique of accelerated training in order to make good our shortage of skilled labour, and it is cold comfort that our techniques, our syllabi, our methods, and even our instructors have been exported overseas to quite a number of under-developed countries in the Commonwealth and outside.

§ 4. Supervisory and Management Training

Moving upwards in the age-scale to supervisory training we find that here my Department has been participating fairly thoroughly. The Training Within Industry (T.W.I.) programmes we borrowed and translated from the United States during the war continue to be by far the largest quantitative contribution to supervisory training. The three original programmes have been entirely re-written, the Job Methods programme to have a slant in the direction of Work Study, and a fourth on Job Safety has now been added. I wish, however, that we had invented a different name for T.W.I., even though that has now become world-famous. I should much prefer something like 'B.T.S.'—Basic Training for Supervisors. Far too many people now have the idea that T.W.I. is a complete programme of supervisory training in itself. It is no such thing. It provides very good grounding in the elements, and by itself, properly used, it is better than nothing. But it is only a foundation upon which management can build, and those who have best succeeded with T.W.I. continue to use it as a foundation upon which to build a fuller and continuous programme of training. I regard it as a success for T.W.I. if a management, having tried it, decides to

replace it by something better, in so far as T.W.I. may have stimulated them to think about the subject on independent lines.

We have, however, also done a certain amount to stimulate industry in this matter. In 1954 we published a Report of the Committee of Inquiry on the Training of Supervisors (Ministry of Labour and National Service 1954), and this has been a useful stimulus to thought, discussion and action. We followed this up two years later with a survey of what had been happening since the Report was published (Ministry of Labour Gazette, August 1956). Both the Report and the survey confirmed that there was quite a lot of study and experiment going on, but quantitatively British industry had not fully wakened up to the need for a thorough-going attitude on supervisory training. My impression is that things are moving a little faster now, but there is certainly a great gap to be filled. There was never a time when the work of the supervisor was more vital, and in so far as training can help, then industry should give it the highest priority.

We come now to the training of middle and upper management. Rather curiously this seems historically to be an off-shoot of supervisory training. Managements have been persuaded into trying supervisory training for junior management and have found it rewarding, and so the idea has spread to higher ranges with growing enthusiasm. I sometimes think that it is not only in the Armed Services that going on a course is a pleasant alternative to the daily round, the common task, but perhaps this is just unworthy cynicism. Certainly executive training has gone ahead very fast in the last ten years. To anyone who knows how long it takes to get new ideas across, it was encouraging to read in the survey done in the north-west of England by the British Institute of Management and the Manchester College of Technology in 1952 and 1953 (British Institute of Management 1953) that 36 per cent of the 112 firms surveyed, employing over 500 workers, claimed to have a management training scheme of some sort. I am certain that this percentage would be much larger today. Not all this activity, I dare say, is well-directed, and even allowing, of course, for the figure of 36 per cent being discounted, " to allow for psychological failure to implement schemes which appeared to be well conceived ", to use the survey's tactful phraseology, it is very far from the 100 per cent which one would like to see.

That Report appended some case studies of Company Executive Development Schemes drawn from all over the country which I should think are as effective as anything you could find in the world today. Some of those here might be inclined to criticize most of these schemes on the ground that they were too strongly impregnated with the British passion for amateur psychology, or at least our deep suspicion of professional psychologists. In the present company I dare not go too deeply into that controversial subject. I have shared those low-brow propensities in my time, and I have partly out-grown them owing to my experience of the brilliant contribution which vocational psychologists can make to the assessment and rehabilitation of the disabled in our Industrial Rehabilitation Units. However, I relapse from time to time when I hear claims, which fortunately are becoming more and more infrequent, for near-infallibility in a field which I resolutely regard on emotional, theological and experiential grounds, to be outside the field of scientific determinism. In brief, I can only feel a genuine affection for psychologists who admit that they are occasionally wrong.

§ 5. Requirements for Extending Training

To sum up my very rapid survey, the picture of training in this country is extremely patchy. In every area of activity you can find examples of as good practice as you would find anywhere in the world, and examples of as bad. The problem is simply to bring as many as possible of them up to the best. It is not just a question of the size of the firm. True, on the whole the big firms, with some rather surprising exceptions, tend to be the shining examples, but some of the best examples of comprehensive training schemes are found in quite small firms. It is not, therefore, a question of a firm having the necessary resources, but of the higher management taking the necessary consecutive interest in the subject.

In any programme for extending and improving training practice in British industry I would therefore put increased personal interest and participation of higher management first every time. How can we get this? We cannot afford to wait until the percentage of resisters has been lowered by death or bankruptcy. There are limits to the encouragement which Government departments can give or managements will tolerate from them, though I must say that British management has been extraordinarily long-suffering about my own Department's efforts in this line. On occasion, management has been quite appreciative. They do realize, I think, that an outsider in our privileged position sees quite a lot of the game, and that we have quite a lot to contribute in the way of collecting and disseminating ideas and methods. Many things have happened in industrial training which have been helped along, even initiated, by my Department, but industrialists are still more ready to lend an ear to other industrialists who have demonstrated that improved training methods not only work but pay dividends as well. One finds, too, that the most rapid progress over the whole field of an industry comes when the employers' association concerned takes a keen interest in the subject, and best of all when it provides advice and even facilities for its members. A bright spot on the horizon has been the growing tendency for employers' associations to do just that.

Beside higher management interest, the other *desiderata* pale into insignificance, but once you have that, they become extremely important. I would not put them in any order of priority because they are all equally important, but I offer these points in a sort of logical sequence:

1. It is necessary to have a clear objective of what the staff are being trained for. This is not quite so obvious as it seems. It is clear that in the case of the worker who is being trained for semi-skilled or unskilled work, the objective is to teach him the right way to do his job in the quickest possible manner, and with modern techniques of job analysis and work study it should not be too difficult to find the solution to that problem.

It becomes more difficult when you come to consider more highly skilled training for apprentices and the like. Traditionally, the apprentice in, say, engineering is supposed to be trained over a fairly wide range of operations within his section of the trade. With increasing specialization in the industry, it becomes increasingly difficult even for a fairly large firm to do this. Can you, in fact, expect management to make the necessary efforts to provide a full range of training, if not within its own works, then by a Group Apprenticeship Scheme in concert with other firms? Or is the impossible task to be left to the Training Colleges of trying to fill in the gaps caused by certain aspects of the trade not

being touched in the apprentices' daily work? Other employers might be inclined to make this effort only in the case of the brighter lad, even though that might mean the possibility of losing him on completion of training. There seems inevitably to be a large element of public-spiritedness in apprenticeship training because of the possibility that the apprentice may be lost to the firm on completion of training. For this reason or other reasons, some firms, including some very large ones in the civil engineering industry and the ship-repairing industry, who train no apprentices of their own, show a notable lack of public spirit. I believe, these exceptions apart, that most of the leading firms seem to find in the long run that the wide range of training is not only socially better and more agreeable to their public spirit, but results in a more contented and effective staff. Even, however, with a wide range of training, one has to have regard to the constant change of processes, and that means regular revision of syllabi of training. In an industry which takes a healthy concern for its future, this point is well looked after on an industry-wide basis.

When you get to management training, this problem of the objective becomes more difficult still. Are you to train your supervisors to be supervisors only, or potential middle-management or higher executives; your middle-management to become senior executives? Are you to train for conformity—'good organization men', to use a recent catch phrase—or to allow an escape hatch for the odd non-conformist genius upon whom the future of the firm will depend? Personally, I do not see an 'either-or' situation here. I do not see why you cannot train people to get on with one another reasonably well (which is what human relations in a large undertaking broadly amounts to) without grinding everyone down to the same level of dull uniformity. Conversely, I see no reason to accept the view (put forward I suspect by geniuses themselves) that the true genius has unlimited licence to be as unpleasant as he wishes. That, however, is open to rejection as a biased opinion of a non-genius. However, the one fallacy to avoid at all costs is the fallacy that all men are or ought to be alike. A management training programme, therefore, has got to be elastic, custom built, one might almost say.

In planning its management training programme, higher management has also got to consider very carefully not only the individual needs of each trainee but the general framework within which he is to operate both now and in the future. To judge by Miss Joan Woodward's (1957, 1958) interesting researches in South-East Essex, it is emerging much more clearly than perhaps we have seen hitherto that the conditions in the process or automatic plant which we can expect to increase in the future will be very different from those in the more traditional type of unit, batch or mass production factory. Major decisions on production will be more onerous because of the impossibility of making rapid subsequent adjustments, but once the plant is set on its new course the executive may have more leisure for what Miss Woodward describes as "the ritual duties so important to the corporate life of a large organisation", and he may even have time for reflection. This also seems likely to apply all the way down the management structure. When the plant is doing most of the work and setting the pace, there will be much less need for pressure upon the individual by the supervisor, and human nature being what it is, this should greatly reduce the sort of frictional trouble with which we are so painfully familiar in most fields of group activity. While, therefore, there will undoubtedly remain a basic

art of management and supervision, so long as it continues to be necessary for one man to take the decisions and another to carry them out—so long, that is, as there are any workers at all in the plant—the form which training in these arts can take in a process or automatic factory may well vary considerably from that in the more traditional type of factory where the task of management is one long pressure upon the individual to push back as far as possible the limitations on production.

2. It is a common experience of life that nothing new ever gets done unless there is someone rooting for it. There is nothing like a pressure group or a vested interest for achieving results. If, therefore, you want a training programme you need to appoint someone who has 'a concern' (as the Quakers say) for training; a full-time training and education officer, if your resources permit. See that he is trained for his job. I have a friend who was to his surprise and alarm appointed to this post in a very large and famous firm because, as a technical specialist, he became restive about the absence of an organized training programme and wrote a memorandum on this subject to his chiefs. He admitted to me that his first task was to train himself. His second was to get a team of instructors whom he has got to have trained in the arts of instruction.

3. Proper training facilities come next. Most leading firms prefer to centre their training of apprentices on an apprentice school. One firm I know has a central apprentice school for basic training and general oversight, augmented by apprentice sections in each of the different specialist shops, through which boys progress to get a thorough training in all processes.

Much of the supervisory and executive training is best given off the job by specialist instructors who may not be available in the firm. Only big firms can afford a Staff College, so there is room either for a number of centres for individual industries or independent colleges run by educational authorities or private trusts.

Two key words come next to my mind: integration and continuity.

4. The ideal training plan is an integrated one, embracing everyone in the firm from the Managing Director to newly joined apprentices, and there are an increasing number of firms which take this as their ideal. I suppose every working group has a greater or lesser tendency to accept the values of its leading elements, and if higher management is seen to be interested in training, both of itself and of others, and to be participating in it, that interest will percolate downwards fairly quickly. An integrated training scheme also has the important feature that when a man has finished a training course he is given an opportunity to exercise his new skills. If he is not given this opportunity his state may be worse than before because he has now added frustration to his existing complexes.

5. Continuity is another necessary ideal, more particularly perhaps in training for management. 'Shot-in-the-arm' training is really useless, not only because of inadequacy in itself, but because of the attitude in the firm which it betokens. I.C.I. provide for a fortnight's training on the average each year for all their supervisors, and as we know, not only from their advertisements, I.C.I. do not lightly throw money away.

§ 6. The Value of Training

This leads me to my last point which perhaps some of you may think I should have tackled earlier. Does training pay? It would be easy enough to

dismiss this with the assumption that of course it does, and must do so, and to point to the analogy from athletics, and so on. One also might point to the results which have been shown in the rather limited number of cases where steps have been taken to evaluate training programmes in this country. That, however, might be a bit of a boomerang because some of these hitherto have produced some unexpected results. Maybe that easy answer is ultimately the right one, but I suggest that it would be rash to accept it too readily, except on the basis that it makes one *feel* good to be trained even if it does not *do* any good. Maybe we should retain a certain basic scepticism in our approach to industrial training, provided, of course, the scepticism does not prevent us from making any approach at all. The raw material of training programmes is the human being, and the human being is and seems likely to continue to be an individual. Furthermore, industry is constantly on the change, and with these two variables to keep an eye on there can clearly be no stereotyped answer, no Procrustean approach, to borrow the title from one of the addresses you are to hear. An attitude of constructive scepticism might be the right attitude of mind to bring to bear on the problems before us. St. Paul's advice to the Thessalonians, "Put all things to the test, hold fast that which is good", is good advice to anyone planning a training programme. It might even be a good motto for the Ergonomics Research Society, if it needs one.

Des tendances actuelles dans les domaines de l'entraînement des apprentis, des ouvriers spécialisés et non spécialisés, pour la surveillance et pour la gérance. L'interêt de la gérance de la société à un niveau plus élevé, la nécessité de se poser des objectifs bien définis, la désignation de fonctionnaires qui soient responsables de l'entraînement, des facilités respectables pour l'entraînement, et l'intégration et la continuité des programmes d'entraînement, sont considérés alors comme les coefficients essentiels de l'entraînement réussi. La question ' Est-ce que l'entraînement se justifie du point de vue de la finance ? ' est discutée.

Die geläufigen Probleme auf dem Gebiete der Anlernung von Lehrlingen, gelernten und ungelernten Arbeitern, Aufsehern und leitenden Angestellten werden diskutiert. Als wichtigste Faktoren für eine erfolgreiche Anlernung werden folgende Punkte herausgestellt: Das Interesse der obersten Werksleitung, die Notwendigkeit klarer Ziele, die Bestimmung von Personen, die für die Anlernung verantwortlich sind und geeignete Anlern-Möglichkeiten. Die Frage: ' Macht sich die Anlernung bezahlt ? ' wird geprüft.

References

British Institute of Management, 1953, *Education and Training in the Field of Management* (London: B.I.M.).

Ministry of Labour and National Service, 1954, *The Training of Supervisors* (London: H.M.S.O.); 1956, Training of supervisors. *Ministry of Labour Gazette*, August; 1958, *Training for Skill* (London: H.M.S.O.).

National Institute of Industrial Psychology, 1957, *Training Factory Workers* (London: Staples Press).

Woodward, J., 1957, Control and communication. A management concept of cybernetics. *J. Instn Prod. Engrs.*, September; 1958, *Management and Technology* (Problems of Progress in Industry No. 3) (London: H.M.S.O.)

PHYSIOLOGICAL BASES OF TRAINING

By Albert Hemingway
Department of Physiology, School of Medicine, University of Leeds

The paper reviews the problem of athletic training in terms of the physiological background. The aim of training is to increase skill, endurance and strength. There may also be factors involved other than these physiological ones.

There are two main types of training :

1. Teaching the individual by imposing a discipline on movements already within his capabilities.
2. Developing the resources of the individual until he can undertake tasks originally beyond his capabilities.

Attention to such factors as length of stride, speed of movements, load and posture can lead to more economical use of the body. Often the most economical rate of performance is that naturally chosen. Improvements in the efficiency of the body often result from training by repetition, or from the use of auxiliary movements.

Strength and endurance are developed only by exercises at or close to the limit of performance. In development training the scheme of training is progressively adjusted to the maximum performance attainable at the different stages of training. Some examples of this are cited in the paper.

In regard to oxygen uptake and heart output, recent work shows that the difference between the trained and untrained man is that the former is able to increase his heart output and transport oxygen to his muscles at a higher rate than the latter. In modern training schemes, economy of effort and strengthening of the heart are achieved by progressive and long continued training. An example is given, based on training for a four-minute mile.

§ 1. Introduction

The effective performance of any piece of muscular work requires a combination, in various proportions, of skill, endurance and strength. Even when viewed within the framework of these three variables the problems of training are manifold. One such problem is: how to enable an individual to undertake a particular task at minimal physiological cost to himself; or again, how to bring to a maximum the amount of work which he can perform for a given and defined physiological cost. Further, there may be the problem of the performance of muscular work in which, within limits, the physiological cost is of no consequence. In artistic expression, for instance, whether the work be the playing of a musical instrument or the use of the body alone, as in dancing or in mime, the concern of the individual is with performance alone; only incidentally with strength and with endurance, and not necessarily at all with mechanical or muscular efficiency. Physiological cost is of interest only to the extent that it may impose a limitation on performance. In some other forms of activity, however, as in athletics, the emphasis on skill may vary according to the branch of sport involved but qualities of strength and endurance will certainly be required if the individual is to surpass the performances of his fellow competitors or opponents. Training, in connection with these latter sorts of physical activity, is concerned not so much with teaching the individual how to use his resources but with the development of them whatever the eventual physiological cost of using them.

Briefly, the theme developed here is that there are two main types of training. One is a teaching of the individual: a disciplining in patterns of movement, which are already within the capabilities of the individual, so that a certain result will be produced. The other type of training is concerned with the development of the resources of the individual so that they are enlarged and he becomes able to undertake tasks which originally were beyond his capabilities.

Industry has employed work study, including time-and-motion study, to lessen fatigue of the worker, to increase his output, or for a combination of the two. All movement, or holding of position by muscular tension, requires the expenditure of energy. The efficiency of muscular contraction, i.e. the ratio between useful work and energy expenditure, varies according to the circumstances in which the muscle is used. Hill (1956) points out that every muscle has two optimum speeds of contraction: one for maximum efficiency, the other for maximum power. But it seems likely that the efficiency of a muscle remains constant if it is used within a given set of parameters and that the efficiency is unaffected by repeated use. It follows from this that any alteration in the efficiency of the body as a whole must come from economical use of its parts and from good coordination when they are used in combination rather than from any alteration in the fundamental properties of the muscle.

A recognition of this simple conclusion is the basis of time-and-motion study. The observer can analyse and appreciate more clearly than the subject, movements which are redundant or poorly coordinated. The relative placing of materials, of the subject and of the 'job' may limit the range of movements which have to be made and their strength and speed. A simple example is the use of a calculating machine where the operator is trained to use the fingers of the left hand while the right hand is free for recording results. Although, initially, the operation of the machine may be easier with the right hand, the repeated change over from manipulation to recording with the same hand is a less efficient cycle of operations than that based on the use of both hands. Training consists in teaching the individual to operate within the cycle which has been planned for him.

§ 2. Optimum Speed of Movement

For many movements there is an optimum speed. One of the first experiments which I recollect performing as an honours student in physiology was to determine my optimum rate of walking, i.e. the most economical speed from the energy point of view. This has been done many times as have similar measurements for cycling and for stair climbing (e.g. Dickinson 1929, Lupton 1923). In a direct application of this principle of 'most economical speed' to industrial conditions, Crowden (1928) investigated the physiological cost and some of the mechanical arrangements of barrow wheeling and found that the most economical rate of wheeling was dependent not only on the speed of walking but upon the load and its position on the barrow.

Quite frequently in investigations of this type it has been found that the naturally selected speed is the most economical and Cathcart *et al.* (1927) showed that alteration in the style of walking could affect its physiological cost. For example, at a constant speed, an increase of 7 per cent in the number of strides per minute caused a rise of 3·75 per cent in metabolic cost while an increase of 11 per cent in striding gave a rise of 7·25 per cent in cost.

Crowden considered further points about load carrying with the wheelbarrow; amongst them the distribution of the load on the barrow and the height of the barrow legs in relation to the body build of the worker. In some respects these considerations were an extension of the classic work of Bedale (1924) and of Cathcart *et al.* (1927) on the relative efficiency of carrying loads in different ways. These authors found that, in general, a symmetrically disposed load distributed so as to bring the centre of gravity of the load over a transverse axis through the feet had an appreciable effect in reducing energy expenditure. Probably even more important, this prevented local fatigue which arose from a distortion of the normal posture of the body. When the subject walked with a marked forward stoop, or with stiff legs, the cost of walking, in terms of oxygen used, increased in some instances by over 33 per cent. It should be emphasized that this overall figure underestimates very much the increase which must have taken place in particular muscles or muscle groups.

These examples have been quoted to show, quite simply, that if the worker is trained according to a few physiological postulates and pays attention to speed of movement, to distribution of load and to posture, then his work can be carried out more economically than would otherwise be the case.

§ 3. Effects of Training

Training is often thought of as implying repetition of movements so that they come to be performed not only more precisely but also more economically. Crowden (1928), in the investigation already mentioned, demonstrated that the oxygen cost of one trip with a loaded barrow decreased progressively as training by repetition continued. Recently, Cotes *et al.* (1958) have reinvestigated the changes in the metabolic cost of walking at a fixed rate during a period of training. They showed not only that it gradually decreases but also that the improvement is due to better coordination of muscles and to the curtailment of waste movements. This supports the earlier findings of Knehr *et al.* (1942). A further point about Crowden's experiments may be that his subjects became stronger during the period of training and that because of this they were better able to maintain equilibrium when walking with the loaded barrow.

A few more quite different examples can be cited of the ways in which an individual is taught to make fuller uses of his capabilities without necessarily extending or improving them. Movements of the head—rotation, extension, flexion—are used to induce, or to reinforce reflexly, tensions or muscular movements in the trunk and limbs. Thus the rapid head-turns used by a ballet dancer in a pirouette are not only an essential part of the convention of the movement but probably cause excitation of nerve end-organs in the semi-circular canals of the inner ear and reflexly affect the tensions in the muscles. If anyone doubts the powerful effects which can be produced through these reflexes he need only rotate himself a few times so that some momentum is imparted to the fluid in his semi-circular canals and then attempt to walk along a straight line. Somewhat similarly, the gymnast or the acrobat will aid speedy flexions or extensions by preceding them with an appropriate movement of the head; and golfers and billiard players, among others, hardly

need to be reminded of the disastrous effects which may follow movements of the head at the wrong moment.

§ 4. The Quality of an Athlete

The type of training already considered is concerned with the efficiency of the subject, either by settling his method of working within some pattern determined by physiological postulates or by improving the co-ordination of his muscles. Another type of training aims at the development of the qualities of the athlete; a consideration of some of the schemes of training employed by athletes to-day will give sufficient examples of the main points to be discussed.

Athletic training aims at developing skill, endurance (and in this respect the efficiency already discussed calls for further consideration), and strength. But Bannister (1956), who is certainly entitled to the expression of an opinion, raises the possibility that factors other than physiological may be concerned with an athlete's performance. He says: the " difference between athletes lies not entirely in differences of cardiac output or diffusion capacity, it lies rather, I suspect, in their ability for mental excitement which brings with it an ability to overcome or ignore the discomfort—even pain—in muscles and the brain which is probably caused by ischaemia and the consequent changes of blood lactate concentration and pH. Though physiology may indicate respiratory and circulatory limits to muscular effort, psychological and other factors beyond the ken of physiology set the razor's edge of defeat or victory and determine how closely an athlete approaches the absolute limits of performance."

This may be so when the limits of competitive endeavour are reached but it seems evident, both from common experience and from more calculated experiment, that strength and endurance are developed only by exercise at, or close to, the limit of performance. Therefore, in most schemes of training in which development is the aim, it is necessary to make a precise assessment of the maximum which is attainable initially, whether it be tension developed in muscle, the distance an implement is thrown, or the time taken to run a given distance. Afterwards, periodically during the period of training, the maximum attainable at that phase of training must be measured again. The scheme of training can then be adjusted to the maximum attainable at that time and to the target which has been set.

§ 5. Development Training

The plan of a scheme can perhaps be shown most easily for weight training (Table 1). The characteristic of the plan is that the training exercises are done in sets, or repetitions, and that the athlete is brought to the limit of his performance at each set (DeLorme and Watkins 1951, MacQueen 1954). In each set of exercises the weight lifted is made heavier and the number of lifts which can be repeated becomes smaller. For example, the weight lifter may begin his training period, after some preliminary limbering-up, by 10 repetitions with a weight which he can just lift ten times (the so-called 10 R.M., the repetition-maximum). The weight is increased by 10–20 lb for the next set and possibly only six or eight repetitions can be made. After a further increase of 10–20 lb perhaps only five or six repetitions will be possible. With each

set the weight is increased by an equal amount, except towards the end when the increments may be smaller, until finally the 'one repetition-maximum' (1 R.M.) is reached. The athlete may then attempt to lift a weight which is some 5 lb above the 1 R.M. and as the training programme progresses this weight will become the new 1 R.M. With the original lowest weight more than 10 repetitions may now have become possible and therefore the starting weight is adjusted to give a new 10 R.M.

Table 1. A Possible Schedule of Training for Weight Lifting

Weight	Probable Repetitions
X	10 [10 R.M.]
$X+Y$	8 (but as many as possible)
$X+2Y$	6
$X+3Y$	3
$X+4Y$	1 [1 R.M.]

R.M. = repetition–maximum.

Somewhat similar principles are applied to the training of distance runners. If an athlete sets the breaking of a record as his aim he knows that he must run at a constant speed for a given time. His problem is whether running at this particular speed will produce fatigue before he has run the distance. The rate of energy expenditure for a particular speed of running is met in part by a current uptake of oxygen and, in part, by the establishment of an oxygen debt which is paid off after the run. The size of the overdraft is limited and when it has been incurred in full, fatigue ensues. The athlete can delay the onset of fatigue and improve his performance in three ways: (*a*) by running more efficiently, i.e. by reducing the energy expenditure required for a particular speed of running; (*b*) by increasing the rate at which he can take up oxygen and transport it to his muscles; (*c*) by adapting himself to a larger oxygen debt. Modern methods of training have been developed empirically but appear to meet these three points. Some authorities would be sceptical about the third possiblity but there is some evidence in its favour (Robinson and Harmon 1941), and a current belief among athletes is that the sensation of fatigue is subjective and can, to some extent, be ignored. This is implicit in the comment of Bannister already quoted.

§ 6. Oxygen Uptake and Heart Output

The transport of oxygen to the muscles is mainly dependent upon the rate at which the heart can pump blood to the muscles. From measurements of the rate of oxygen uptake for work at different intensities, and from corresponding estimates of the output of the heart, a linear relationship between the two has been postulated (Christensen 1931a, b, Bock *et al.* 1928, Asmussen and Nielsen 1955). Recently, by the use of new techniques, the heart output, over a limited range, has been measured more directly and the relationship confirmed (Donald *et al.* 1955, Freedman *et al.* 1955). The latter authors also demonstrated what had previously been suspected but not proved, viz. that in the healthy subject this relationship is unaffected by training (Fig. 1). Therefore an essential difference between the trained and the untrained man

is not that their hearts behave dissimilarly but that the former is able to move further up the line; he is able to increase the output of his heart. Because of this he has the potentiality of transporting oxygen to his muscles at a higher rate than the untrained man.

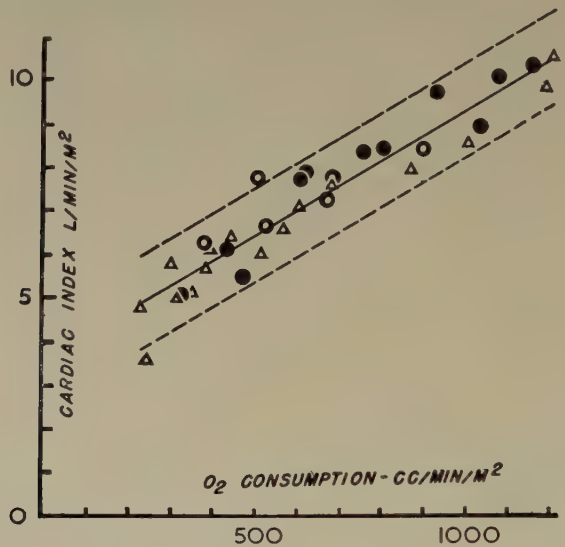


Figure 1. Relationship between cardiac output and oxygen consumption for trained and untrained subjects. △, untrained subjects (Donald *et al.* 1955); ○, untrained subjects, ● trained subjects (Freedman *et al.* 1955). (Modified from Freedman *et al.* 1955.)

§ 7. Training Schemes

Examination of a modern scheme of training for distance running, such as that set out by Stampfl (1955) (Table 2) will show how the coach and the athlete attempt to achieve economy of effort and strengthening of the heart by progressive and long continued training. The scheme is one to prepare a runner for a four-minute mile. Its pattern is: a preliminary period of training to develop a general fitness followed by special training for the mile run. Easy cross-country running is merged into a Swedish system of cross-country work (Fartlek) in which short sprints or fairly fast quarter-mile runs are interspersed with longer runs at a slower speed.

The period of track training extends over seven months; in this phase of training the athlete comes to the task of accustoming himself to running at a particular speed which is raised progressively month by month. Two techniques, interval running and repetition running, are employed in this progression. They are similar in that both of them give the athlete practice in running at, or close to, the speed he would be likely to use in a race at his current fitness. They differ because in interval running a relatively short distance, in this case 440 yards, is run at a high set speed and the same distance is then run at a speed slow enough to allow recovery. The sequence of fast run–slow run is repeated without break for perhaps ten times in one training session. An essential of this part of the training seems to be that, at the particular speed selected, the distance, the recovery period and the number of repetitions are adjusted so that the athlete is not unduly fatigued and can obtain the maximum

amount of ‘experience’ of running at a particular speed. In other words, the development of skill takes precedence over the development of endurance and strength.

Table 2. A Scheme of Training for an Athlete Preparing to run a Mile in 4 min. Based on Stampfl (1955)

Cross Country Running (Fartlek)							
	Months						
	1	2	3	4	5	6	7
Interval Running 10 repetitions							
440 yd fast run	70	68	66	64	62	61	60 sec
440 yd recovery run				2·5–3·0	min		
Repetition Running							
880 yd	2.20	2.16	2.12	2.10	2.08	2.06	2.04 min sec
No. of repetitions	6	6	6	6	6	5	5
$\frac{3}{4}$ mile		3.35	3.30	3.25	3.20	3.15	min sec
No. of repetitions		4	4	4	4	3	

In repetition running there is a similar emphasis on running at a particular speed, but the distance of the run is increased and the run is followed by a period of rest long enough for recovery as judged by the return of heart rate and breathing to near the original rate. Runs of $\frac{1}{2}$ and $\frac{3}{4}$ mile are prescribed, with six repetitions of the former and four of the latter distance. In these runs the athlete is brought closer to the point of fatigue in each run than he is in interval running because the speed is set on the assumption that he would be almost exhausted if the full distance were run. There is a close resemblance between the repetition of these almost maximal efforts and the progression which is followed in weight training.

As the fitness of the athlete increases and his performance improves the duration of the periods for both interval and repetition running are decreased. The former is set to produce the average speed at which a race over the full distance ought to be run. The latter is set to stress the circulatory and respiratory systems as strongly as possible.

§ 8. Conclusions

Three questions remain to be answered. How and to what extent do these training methods differ from those formerly used? Do they produce better results? Can these methods be improved? The differences from former training methods seem to be (*a*) the athlete is given more opportunity to practice at racing speed, (*b*) more allowance is made for the athlete to run in his natural style, (*c*) the athlete deliberately runs close to his fatigue point on a number of occasions in one training session.

At the moment one can only conjecture about some of these problems. There is no direct evidence that running is carried out more efficiently because

of practice at a particular speed. Reference has been made already to the work on walking, and Dill *et al.* (1930) showed that in a group of subjects who ran at the same speed on a treadmill the most efficient was a recognized athlete in training; but there are no records which trace alterations in efficiency through a period of training. That efficiency can be affected by style of running was shown by Högberg (1952) who demonstrated that there was an optimum stride length for a given speed of running.

When the question of heart output in relation to training is examined there is the same difficulty arising from the lack of a progressive series of observations made during training. There is evidence from the track and the laboratory that, as training progresses, increase in heart rate is smaller and recovery more rapid when the subject is exposed to a test. The maximum rate of oxygen uptake increases and the subject can run for a longer period at a given speed, or can run farther in a given period. Within the limits of observation, the heart output is known to be in linear relationship to oxygen uptake.

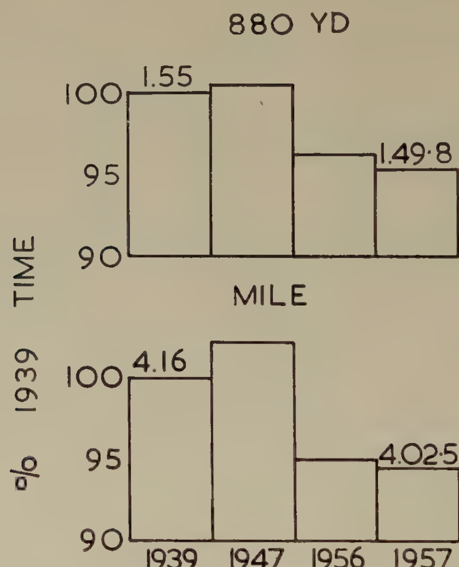


Figure 2. Showing the mean of the best times (min sec) for the 10 top runners during seasons 1939, 1947, 1956 and 1957. The times are expressed as percentages of the 1939 times. (Based on McWhirter 1957.)

There is no doubt that the standard of athletic performance has improved; not only for the world champions but for the average athlete. The mean of the best performances for the half-mile and mile races from the top ten British athletes each year shows an improvement of about 5 per cent over the last ten years (Fig. 2, McWhirter 1957). Is this improvement causally related to methods of training ?

To end on a note of scepticism it should be pointed out that speed and endurance in animal athletes—horses and dogs—seems to depend at least as much on breeding and on selection as on methods of training (Strangeways 1954).

On revoit le problème de l'entraînement athlètique par rapport aux données physiologiques. Le but de l'entraînement est d'augmenter l'adresse, la résistance et la force. Il peut y avoir d'autres coefficients en jeu aussi bien que ces éléments physiologiques.

Il y a deux espèces principales d'entraînement:

1. On enseigne l'individu en imposant une discipline à des mouvements dont il est déjà capable.
2. On développe les capacités de l'individu jusq'à ce qu'il peut entreprendre des tâches qui étaient auparavant hors de sa capacité.

L'étude de certains facteurs comme la longueur de l'enjambée, la vitesse des mouvements, le poids du fardeau et la posture peut mener à l'utilisation plus économique du corps. Souvent le train de rendement le plus économique est celui qui est choisi spontanément. Des améliorations dans la compétence du corps résultent souvent de l'entraînement par repetition, ou de l'emploi de mouvements auxiliares.

La force et l'endurance ne se développent que par des exercices à la limite ou près de la limite du rendement possible. Dans l'entraînement de développement le plan de l'entraînement est ajusté au maximum qu'on peut atteindre instantanément. On cite quelques exemples.

Quant à la prise d'oxygène et le débit du coeur, le travail récent montre que la différence entre l'homme entraîné et l'homme non entraîné est que le premier peut augmenter le débit de son coeur et transporter l'oxygène à ses muscles à plus grande vitesse que ce dernier. Dans les systèmes d'entraînement modernes, l'économie de l'effort et l'accroissement de force au coeur sont atteints par l'entraînement progressive et de longue durée. On donne un exemple, fondé sur l'entraînement pour une course d'un mille un quatre minutes.

Die Arbeit gibt eine Uebersicht über die physiologischen Probleme des sportlichen Trainings. Der Zweck des Trainings ist es, Geschicklichkeit, Ausdauer und Stärke zu erhöhen. Natürlich können andere Faktoren eine Rolle spielen als die rein physiologischen.

Zwei Haupt-Typen des Trainings sind zu unterscheiden:

1. Das Anlernen eines Individuums an einen Bewegungsablauf der schon in seinen Leistungsmöglichkeiten liegt.
2. Die Entwicklung der Fähigkeiten eines Individuums, derart, dasses Aufgaben übernehmen kann, die ursprünglich nicht in seiner Leistungsmöglichkeit standen.

Die Beachtung von Faktoren, wie Weglänge, Bewegeungsgeschwindigkeit, Last und Körperstellung können zu einer ökonomischeren Nutzung des Körpers führen. Oft ist die freiwillig gewählte Arbeitsgeschwindigkeit die ökonomischte. Oft führt auch wiederholte Ausübung zur Verbesserung des Wirkungsgrades, oder es ist nützlich, Hilfsbewegungen einzuführen.

Kraft und Ausdauer werden nur durch Uebungen verbessert, die dicht unter der Grenze der Leistungsmöglichkeit liegen. Bei progressivem Training wird das Trainings-Schema dem jeweils möglichen Leistungs-Maximum angepasst. Einige Beispiele dafür werden angeführt.

In Bezug auf die Sauerstoff-Aufnahme und das Herzminutenvolumen haben neuere Arbeiten gezeigt, dass der Unterschied zwischen einem trainierten und einem untrainierten Mann darin liegt, dass der erstere sein Herzminutenvolumen und den Sauerstoff-Transport zu seinen Muskeln auf eine höhere Stufe bringen kann. In modernen Trainingsmethoden werden ein ökonomischer Muskeleinsatz und ein starkes Herz durch progressives und lang-fortgesetztes Training erreicht. Ein Beispiel wird angeführt, wie ein Mann trainiert wird, eine Meile in 4 min zu laufen.

References

Asmussen, E., and Nielsen, M., 1955, Cardiac output during muscular work and its regulation. *Physiol. Rev.*, **35**, 778–800.

Bannister, R. G., 1956, Muscular effort. *Brit. med. Bull.*, **12**, 222–225.

Bedale, Elizabeth M., 1924, The effects of posture and rest on muscular work. *Med. Res. Council. Industr. Fatigue Res. Bd. Rep.* 29.

Bock, A. V., Vancaulaert, C., Dill, D. B., Folling, A., and Hurxthal, L. M., 1928, Studies in muscular activity. III. Dynamical changes occurring in man at work. *J. Physiol.*, **66**, 136–161.

Cathcart, E. P., Bedale, Elizabeth M., Blair, C., Macleod, K., and Weatherhead, E., 1927, The physique of women in industry (A contribution towards the determination of the optimum load). *Med. Res. Council. Industr. Fatigue Res. Bd. Rep.* 44.

Christensen, E. H., 1931 a, Gasanalytische methoden zur bestimmung des Herzminutenvolumens in Ruhe und wahrend körperlicher Arbeit. *Arbeitsphysiologie*, **4**, 175–202; 1931 b, Minutenvolumen und Schlagvolumen des Herzens während schwerer körperlicher Arbeit. *Arbeitsphysiologie*, **4**, 470–502.

Cotes, J. E., Meade, F., and Wise, M. E., 1958, Variations, in the vertical work done against gravity and in the energy expenditure of walking, between men and women in relation to training. *J. Physiol.*, **141**, 28 P.

Crowden, G. P., 1928, The physiological cost of the muscular movements involved in barrow work. *Med. Res. Council. Industr. Fatigue Res. Bd. Rep.* 50.

DeLorme, T. L., and Watkins, A. L., 1951, *Progressive resistance exercise: technic and medical applications* (New York: Appleton-Century-Crofts Inc.).

Dickinson, Sylvia, 1929, The efficiency of bicycle pedalling as affected by speed and load. *J. Physiol.*, **67**, 242–255.

Dill, D. B., Talbott, J. H., and Edwards, H. T., 1930, Studies in muscular activity. VI. Response of several individuals to a fixed task. *J. Physiol.*, **69**, 267–305.

Donald, K. W., Bishop, J. M., Cumming, G., and Wade, O. L., 1955, The effects of exercise on the cardiac output and circulatory mechanics of normal subjects. *Clin. Sci.*, **14**, 37–73.

Freedman, M. E., Snider, G. L., Brostoff, P., Kimelblot, S., and Katz, L. N., 1955, Effects of training on response of cardiac output to muscular exercise in athletes. *J. appl. Physiol.*, **8**, 37–47.

Hill, A. V., 1956, Design of muscles. *Brit. med. Bull.*, **12**, 165–166.

Högberg, P., 1952, How do stride length and stride frequency influence the energy-output during running ? *Arbeitsphysiologie*, **14**, 437–441.

Knehr, C. A., Dill, D. B., and Neufeld, W., 1942, Training and its effect on man at rest and work. *Amer. J. Physiol.*, **136**, 148–156.

Lupton, H., 1923, An analysis of the effects of speed on the mechanical efficiency of human muscular movement. *J. Physiol.*, **57**, 337–349.

MacQueen, I. J., 1954, Recent advances in the technique of progressive resistance exercise. *Brit. med. J.*, **2**, 1193–1198.

McWhirter, N., 1957. *A.A.A. Coaching Newsletter*, Nov. 1957.

Robinson, S., and Harmon, P. M., 1941, The lactic acid mechanism and certain properties of the blood in relation to training. *Amer. J. Physiol.*, **132**, 757–769.

Stampfl, F., 1955, *Running* (London: Jenkins).

Strangeways, Dorothy H., 1954, Ed. Symp., The physiology of athletic training. *Advanc. Sci. Lond.*, **40**, 407–420.

TRAINING OPERATIVES IN INDUSTRY

By W. Douglas Seymour

Clent, Worcestershire

Recent researches have shown the importance of the perceptual component in skilled performance on industrial tasks, and have indicated the ways in which the operator adapts his capacities in improving his level of skill. The methods by which this new knowledge is used in systematic training schemes based on skills analysis are described, and some current problems in industry reviewed.

§ 1. Ergonomics and Industrial Skills

The principal aim of Ergonomics is to adapt the task to the capacities of the human operator; the principal aim of training is to adapt the capacities of the operator to the task. The two are thus complementary, and in industry the simplification of jobs, improved working methods and improved training are all closely linked. But in considering training for industrial operations as they exist, we have to determine two things: first, how does the operator improve in skill, i.e. adapt his capacities to the task; and second, under what conditions is the development of his skills best facilitated ?

A survey of repetitive, productive, so-called semi-skilled jobs in industry reveals that most of them can be performed in a fashion by most people, but that few people attain the standards of speed and quality demanded of, and attained by, experienced workers. More detailed study of typical industrial tasks indicates (Seymour 1954 a) that the speed skills depend more on mastering the perceptual requirements of the task than on merely performing the movements involved. Experienced workers differ from learners not so much in the movements they make, nor in the speed of those movements, as in the manner in which they use their senses to derive information from the task for controlling the movements. The learning of the sequence of activities in an industrial task usually involves much less difficulty than acquiring the perceptual skills (Seymour 1954 b). Having learned the sequence of activities required in the task and adopted a pattern of movements to achieve them, the trainee has to establish a pattern of perceptions to provide the necessary information for initiating each movement, controlling it, and terminating it (Crossman 1956). As a pre-requisite to the establishment of this pattern, the trainee has to determine the locus of each item of information and the sensory channel through which it is to be acquired, and may need to develop a special level of adaptation in the sensory channel itself. Frequently, as performance improves, the channel is changed—particularly from visual to proprioceptive perception. These perceptual changes interact with movements, the pattern of which may need to be altered to conform with the new perceptual pattern. As higher levels of skill are reached, less information is needed from the task; quite complex movements patterns are ‘ triggered off ’ from single stimuli, and attention is focused on the details of the task only when they are abnormal (Crossman and Seymour 1958). Meanwhile, speed of performance improves by the repetitions of each movement, conforming more and more frequently to the

optimum, apparently by means of a selective process by which the most appropriate muscle groups are chosen (Seymour 1957).

Certain of the conditions which may facilitate this development of speed skill have been investigated (Seymour 1954 b). On a capstan lathe it was found that ' part ' methods offered no advantage over ' whole ' methods where the task was principally one of movement, but that where the task was perceptually stringent—which is normally the case—part methods were superior. The isolation of perceptually difficult elements in a task, without formal division into all the separate parts, has been found to give results almost equal to those from part methods, and has been used in field experiments (Belbin *et al.* 1957).

Part methods would be of little help if the subsequent combination of the parts led to a fall in performance, but recent experimental results indicate that there is little decrease when the parts of a task are combined (Gagne 1947).

As many experimenters have found, one of the most important factors facilitating the acquisition of skill is the provision of knowledge of results achieved, and this is probably the least controversial of the conditions of learning.

Intelligence, as measured by non-verbal intelligence tests, has been found to have no significant influence on the trainee's acquisition of skill on the capstan lathe (Seymour 1954 b). But the social conditions in which training takes place are considered by King (1948) and others to be of major importance. The topics of motivation and incentives are omitted from this discussion as not belonging exclusively in the field of training.

§ 2. Practical Applications

Researches in psychology and physiology are of little use in industry unless ways and means can be found to apply them effectively, and all too frequently it is not lack of knowledge but lack of its application which hampers the effective use of the human operator in industry. However, it would probably be true to say that, during and since the war, industrialists in Great Britain, more than in any other country, have made effective use of new knowledge about skill and training. In general, they have been receptive to new ideas, prompted by the scarcity of labour, the high rate of labour turnover and the need to increase productivity.

We shall here deal with what have come to be known as specialized or analytical methods of operator training. This approach is due to Dr. A. H. Seymour, who in 1942, with experience derived from psychology, work study and industrial administration, first thought out the fundamental principles.

These principles may be summarized thus:

1. The training of operatives should be based on a detailed analysis of the skills of the experienced worker. This is axiomatic. Since the purpose of operator training is to enable recruits to attain as soon as possible the level of output and quality of experienced operators, it is reasonable to suppose that this aim will be more readily attained if the objective is recognised and carefully observed. The analysis of experienced workers' skills can be performed much more thoroughly now than was possible fifteen years ago, and the more fully skills are analysed, the better the basis for designing the training

course. Moreover, as a result of more widespread use of work study, methods of work are now more explicit and more consistent, and standards of work are subjected to better means of measurement.

2. Preliminary training exercises should, in certain cases, be used prior to attempting the operation. Such exercises, frequently performed on specially designed devices, are used when elements of the task involve unusual levels of sensory adaptation or perceptual stringency, or to provide ' feed back ' not otherwise available, or to isolate especially difficult elements in a task.

3. The operation should be taught in detail, and practised in parts or sections. The total operation should be built up when, and only when, these parts have been performed to the experienced workers' standard of proficiency. Part methods of training are used, not only for the reasons based on the experiments mentioned above, but also for the following practical reasons:

(*a*) When one starts to teach recruits ' how ' a job is done, and not merely ' what ' is done, by an experienced worker, the amount of detailed instruction required, even on so-called simple jobs, is so great that one is driven, out of consideration for the trainee, to teach only a part at a time, especially when the perceptual requirements are not readily recognizable.

(*b*) Few operators in industry are required to perform a task which consists of a single entity. In most assembly work, and in all but single-purpose machine jobs, there is no single ' whole ' to the task, and operators have to be able to perform a variety of tasks, each of which is comprised of a different combination from a repertory of parts.

(*c*) Part methods, and the recording of performance time against the ' target ' of experienced workers' speed, provide immediate and frequent knowledge of results.

(*d*) The disadvantages traditionally associated with part methods can be overcome by ' progressive part ' methods (Seymour 1954 c).

(*e*) By programming the parts and exercises to be practised at different times in the day, ' spaced ' learning can be used, with its undoubted advantages. Detailed programmes and records also facilitate the supervision of training.

4. Training should continue until the experienced workers' standard is maintained for a day or more.

5. Systematic training should be given on the quality requirements of the operation as well as training for speed. When the elements of a task have been combined and the operation can be correctly performed throughout at experienced worker's standard, the duration of performance is progressively increased until a day's, later a week's, work can be satisfactorily completed. Meanwhile the training on quality standards is continued with the aid of a Quality Specification and Fault Analysis (Seymour 1954 c).

The precise ways in which these principles can be applied in practical work situations vary with the category of operation considered and upon local conditions. Specialized or analytical training methods have, however, been used for hand work with and without tools, for work with single-purpose and

multi-purpose machines, and for group machine work. They have been used in a wide range of industries including mechanical and electrical engineering (Seymour 1956), telecommunications, screw-making, pottery, hosiery, garment and footwear manufacture, knitting, weaving and spinning and the tobacco industry.

The major difficulty lies not in our ignorance of skill and its acquisition, but in finding appropriate and economical ways of employing new knowledge in an industrial context. Some of the ways in which this has been done are exemplified in subsequent papers, but it must be emphasized that training courses need to be ' made to measure ' to suit each industry, although within the same industry an existing training course can be adapted by experienced personnel to suit the requirements of other firms.

In most industries, specialized or analytical methods of training have been developed within individual firms, and in most industries this is essential, since each firm's requirements are different. But where the units of an industry use similar processes, similar machines and similar methods—as in spinning, weaving and the shoe industry—there is much to be gained by tackling operator training through some central body of the industry. This is not only the most economical way of developing training, but it helps an industry to raise the general level of skill, to achieve more consistent standards of productivity, and lessens the likelihood of firms enticing trained labour from competitors.

It has been found possible by the use of these techniques, to reduce the time required for new recruits to attain the experienced worker's level of performance to about half or a third of the time previously required.

A reduction in training time of this order, coupled with the higher productivity achieved, leads to economies which in general far outweigh the cost of setting up training schemes. These economies arise through a reduction in direct labour cost, and an increase in overhead recovery. In certain cases the economy from better utilization of material and improved quality outweigh all other financial savings, and the installation of such improved training has, in instances where records were available, been associated with a reduction in labour turnover, and an increase in the ' yield ' of trained workers.

§ 3. Current Developments

New problems are still frequently encountered when applying these methods in industries where they have not been used before, and some need further experiment for their solution, for example, that of training machinists for bespoke tailoring and for certain operations in the rubber industry. Such problems seem generally to contain as their nucleus a factor of unpredictable variability in the material being handled.

The increasing rate of change in market requirements for products has introduced recently an especial need for ' transfer training '—the training of existing workers on new and different jobs. Similarly, technological change brings with it the need for training existing workers to perform the same operations by completely new methods. This most commonly occurs where special purpose ' combine ' machines are introduced to perform what previously was achieved by a number of different processes. Again, the introduction of automatic transfer machines, although it usually simplifies the operations to

be performed, brings added difficulties in the economical organization of training, and these problems are being carefully studied at the present time.

Des recherches récentes ont démontré l'importance de l'élement de perception dans l'accomplissement spécialisé des tâches industrielles, et indiqué les moyens par lesquels l'opérateur adapte ses capacités tout en réhaussant son niveau d'habileté. Il s'agit ici de décrire les méthodes par lesquelles ces nouvelles connaissances seront à utiliser dans les projets systématiques d'entraînement qui se fondent sur l'analyse de l'habileté; on passe aussi en revue quelques problèmes de l'industrie contemporaine.

Neuere Forschungen haben die Wichtigkeit der Wahrnehmungskomponente bei Geschicklichkeitsaufgaben in der industriellen Fertigung gezeigt, und haben die Wege deutlich gemacht, auf denen der Arbeiter seine Leistungsfähigkeit ampasst, in dem er die Höhe seiner Geschicklichkeit verbessert. Es werden die Methoden beschrieben, mit denen diese neue Erkenntnis in systematischen Anlernverfahren aufgrund einer Geschicklichkeitsanalyse ausgenutzt wird. Einige geläufige Probleme der Industrie werden in neuer Sicht behandelt.

References

Belbin, E., Belbin, R. M., and Hill, F., 1957, A comparison between the results of three different methods of operator training. *Ergonomics*, **1**, 39–50.

Crossman, E. R. F. W., 1956, Perceptual activity in manual work. *Research*, **9**, 42–49.

Crossman, E. R. F. W., and Seymour, W. D., 1958, *The Nature and Acquisition of Industrial Skills* (Birmingham University) (unpublished).

Gagne, R. M., 1947, Transfer of training from practice on the components of a motor skill. *Report No. 2, U.S. Naval Medical Research Laboratory* (New London, Connecticut).

King, Pearl H. M., 1948, Task perception and interpersonal relations in industrial training. *Human Relations*, **1**, 373–412.

Seymour, W. D., 1954 a, Manual skills and industrial productivity. *J. Instn Prod. Engng*, **33**, 240–248 ; 1954 b, Experiments on the acquisition of industrial skills. Part 1, *Occup. Psych.*, **28**, 77–89 ; Part 2, *Ibid.*, **29**, 82–98 ; Part 3, *Ibid.*, **30**, 94–104 ; 1954 c, *Industrial Training for Manual Operations* (London : Pitman) ; 1956, Training operators in the engineering industry. *Engineering*, **182**, 1–4 ; 1957, Transfer of training in engineering skills, *Occup. Psych.*, **31**, 243–247.

THE TRAINING OF SHOE-MACHINISTS

By W. T. Singleton

The British Boot, Shoe and Allied Trades Research Association, Kettering

A training scheme for sewing-machinists based on the 'progressive-part' method is described. It was tested in preliminary training courses run by the Research Association to which the author belongs, and was then spread throughout the industry by organizing a series of training courses for instructresses. These instructresses are selected by the parent firm or technical college, they are trained in the procedures of the scheme and then return to their factories or colleges to set up their own training schools.

The main difficulties of this work have not been connected with the finding of successful training procedures, but with the initiation and maintenance of training schools in the industry. The problems which arise and some measures which have been devised for dealing with them are outlined.

§ 1. Introduction

In 1954 this Research Association was faced with the problem of improving the training procedures used in the shoe-industry. It was decided that the work should be concentrated on shoe-machinists for two main reasons: there was a universal shortage of skilled operatives for these tasks and the basic task itself is required in every factory. Although the majority of shoemaking firms are small, with an average size of less than 200 operatives, there are a few large ones and several of these were already using formal training methods.

The first task was to visit and study the advanced firms. In the formal training schemes investigated there was one particularly disturbing feature. The training-schools, often installed in the first place by management consultants and, as far as could be determined, effectively, seemed to deteriorate when the consultants left the factory. The main reasons for this were that the benefits of systematic training methods are long-term rather than immediate, and the instructor or training officer was usually too junior a member of the organization to be able to defend the status of training effectively. The training staff had often been originally recruited from production staff and there was a natural tendency for them to be taken from training work to meet sudden emergencies in production supervision. Similarly the training school was too readily available as a source of additional production capacity or spare machinery.

A number of factories using the 'exposure' method of training were visited. This traditional practice of placing a newcomer next to an experienced operative was found to be unsatisfactory from both the trainee's and the teacher's point of view. The trainee gets insufficient attention so that in many cases she quickly begins to lose interest in the job. She may also become confused by receiving help from a number of skilled machinists each of whom may have her own ideas and her own methods. At the same time she picks up a variety of bad habits which may be tolerable in a highly-skilled machinist, but which detract considerably from the performance of a learner. The teacher's position is equally unsatisfactory. She is often on piecework and is caused to spend her time helping the trainee. She may have no interest or ability in teaching

and she may even feel some reluctance to convey to the newcomer the skill which it has taken her many years to develop. In general, this training is entirely unplanned so that it is not surprising that the trainee takes at least a year to become skilled even on the simpler sewing operations.

§ 2. Design of a Training Scheme

At the end of this preliminary survey two alternative procedures were possible: either to initiate a rigorous series of long-term experiments on the suitability of various training methods, but it was clear that little could be achieved by this method within the three-year project allowed by the grant under which the work was being done; or to design a training scheme on a more *ad hoc* basis, relying on the experience of other workers in this field—particularly W. D. Seymour—and on the experience gained in the survey. The latter was chosen, and a training scheme was designed quite rapidly on the following principles:

(*a*) That a separate training school was necessary.

(*b*) That a skilled full-time instructress was necessary.

(*c*) That the 'progressive part' method of training should be used.

(*d*) That target times and quality standards should be provided for all stages of the training course.

(*e*) That standardized 'best' methods should be developed on orthodox work-study principles.

(*f*) That visual aids such as films and film-strips should be used in the teaching of correct procedures.

The scheme can be summarized in the following four stages.

1. Instruction in the basic skills of positioning, guiding, machine control and machine servicing is given by utilizing training devices and exercises which isolate the appropriate part of the task.

2. The positioning, guiding and machine control skills are then combined in stitching exercises without thread.

3. The machine servicing skill is then added by using stitching exercises with thread, beginning on training curves and proceeding on simple shoe machining operations on fibre components cut to resemble orthodox shoe components.

4. Lectures and visual aids are used to acquaint the trainees with the appropriate technological factors. This knowledge is combined with the manual parts of the skill by carrying out the last part of the training on production work of the kind which the trainees will be expected to do in the factory.

This scheme was tried during three Machinist Training Courses for school-leavers who were sent by local factories. At the end of the courses the trainees went on to production work in their factories and had no difficulty in earning adequate wages on the piecework system; in fact, there was some difficulty of relations with other operatives who, although some years older, were unable to earn as much as properly trained machinists. In this way the usefulness of

the training scheme as a method of inculating the basic skills was demonstrated. Throughout these trial training courses the basic scheme remained the same, although a number of minor alterations were made for each successive course. These changes were made on the basis of the experience of the instructress and the project leader who were careful to note all the minor defects which became obvious during each course, and tried to determine their origin.

§ 3. Extending the Scheme to Industry

After the third course it was decided that the problems of establishing and maintaining a modern training system in the industry, with its wide geographic distribution and six hundred or more factories, should be explored. Apart from the positive advantages of doing this in order to gain the support of the industry by the end of the three-year period, there would have been serious practical difficulties in carrying out formal research on the method of training. In particular, the maximum number of trainees which could be accommodated at one time was six, which is not large enough for an adequately controlled experiment within a single course. The fact that new entrants into the industry come mainly at the end of each school term meant that only about four courses could be run in any one year. Thus, if any modifications were to be validated experimentally over a succession of courses, it was clear that a period of some years would be likely to be required for much progress to be made.

A course was therefore organized for instructresses and instructors with the object of giving them three weeks' training on how to run a training school, and then sending them back to their firms to set up their own schools. The three weeks were spent in explaining the training scheme, in ensuring that each one could attain the set target for all the training exercises, and in teaching them how to administer the exercises and coach the trainees. Within two months of the return to their factories four of the five entrants had set up training schools and were running training courses, with occasional visits from the Research Association's training staff.

This course set a precedent which has been followed through four additional courses so that there are now twenty-nine trained instructors or instructresses available in the industry, the majority of whom are now running their own training schools. Many of these are in the larger shoe factories, some are in technical schools in the shoe-making areas of this country. The adoption of the training system by the technical schools is a recent important development which provides a way of making the system available to the majority of firms in the industry which are too small to start their own schools. This is the first time that an intensive operative training system has been introduced into technical school curricula in this country. The step has been approved by the appropriate education authorities.

§ 4. Results of the Training Scheme in the Industry

The project proceeded on the assumption that there is already sufficient knowledge of training available for a significant impact to be made on the industry if this knowledge could be applied. The validity of this assumption has been demonstrated by the fact that, using a rapidly designed training scheme,

the period of training required for elementary machining has been reduced from a year or more to six or eight weeks. The major problem was judged to be that of application and in this phase of the work, even more than in the development of the training system itself, a formal scientific approach was impracticable. The project has progressed by using the degree of success in practice as a validation criterion rather than by the comparison of experimental groups.

The quality of the training given by the factory schools has been mixed. About half can be regarded as satisfactory at present; the remainder display the same kind of shortcomings as were observed in our preliminary survey of existing training schools, despite the fact that the new schools have the advantages of continued association with, and advice from, the Research Association and of a training system worked out in considerable detail and designed to be reasonably easy to administer. The main reasons for the mediocre results obtained by some of the schools are, in order of importance:

(i) a variety of administrative difficulties, including insufficient or unsuitable trainees;

(ii) lack of effective support and understanding from the management;

(iii) doubtful suitability of some of the instructors, most of whom have been chosen by the firms from existing staff—mainly machinists, sample hands or supervisors.

The most common administrative difficulty has been that firms wish to take the training too far too quickly. It is often the case that a factory has an adequate labour force for the simpler sewing operations but a shortage of highly skilled versatile labour. Thus there were several attempts to train beginners to the level of advanced work by prolonging the course beyond the intended six to eight weeks. We watched these attempts with interest but they have had little or no success and we are now satisfied that initial training should be confined to elementary work and should be followed by a period in the production department before further training to a more advanced level is attempted.

These remarks should not be taken as signifying that the attempt to establish factory training schools has failed. Many of them are very successful and the project has certainly been successful by one significant criterion—the work continues with financial support by the industry.

There are several advantages in organizing training through the technical schools:

(i) the instructors are mainly experienced teachers;

(ii) the staffs of the schools, unlike factory staffs, have no responsibilities outside the field of education and training;

(iii) since trainees from many local firms are available it is less difficult to organize regular courses at maximum capacity.

There are also some disadvantages:

(i) it is less easy to maintain discipline;

(ii) a regular supply of work for the ‘ production ’ stage of training is less readily obtained.

(iii) it is more difficult to exchange information with and get cooperation from factory staffs during the important period following the transfer from training school to factory.

It is too early to assess the relative importance of these various factors, but the development of this part of the scheme will be observed with particular interest.

Behind the administrative and directly applied work which inevitably takes up most of the available time on this project, it is now possible to introduce studies of more fundamental aspects which should yield results of theoretical interest. For example, an experiment is in progress on the relative effectiveness of training throughout at high speed with consistently improving quality of work as an alternative to high quality standards with steadily increasing speed. Data has also been accumulated relevant to the more rigorous validation of the scheme.

Apart from the author, who has been concerned mainly in a specialist advisory capacity, this project has involved a number of Association Staff. The project leader in the first half of the three-year period was Mr. J. M. Hamilton; during the second half, Mr. T. F. Watson. Miss T. Penn is the permanent instructress. Mr. H. Bradley, Director, Mr. D. Grimwade, Deputy Director; and Mr. F. G. Bailey, Leader of the Industrial Division, were concerned not only in the general policy decisions which marked the various stages of the work but also in some detail in the design and application of the training scheme. The work was supported by a grant made by the M.R.C. and D.S.I.R. Joint Committee on Individual Efficiency in Industry from American Conditional Aid Funds.

Description d'un système d'entraînement pour les opérateurs de machines a coudre, fondé sur la méthode des ' parties progressives '. On a essayé ce système dans des cours d'entraînement préliminaire organisés par l'Association pour les Recherches à laquelle appartient l'auteur, et ensuite on l'a répandu parmi l'industrie entière en organisant une série de cours d'entraînement pour les instructrices. Ces instructrices sont choisies par la maison sociale ou par l'école des arts et des métiers, elles sont entraînées dans les procédés du système et alors elles reviennent à leur fabrique ou à leur école pour instituer leurs propres cours d'entraînement.

Les difficultés principales de ce travail ne se rapportent pas à l'évolution de procédés efficaces d'entraînement mais à l'inauguration et à la continuation de cours d'entraînement dans l'industrie. Les problèmes qui se posent et quelques contremesures que l'on a trouvées sont décrits.

Es wird ein Ausbildungsschema für Maschinen-Näherinnen beschrieben, das auf einer fortschreitenden Teilausbildung beruht. Dieses Schema wurde zunächst in Ausbildungskursen ausprobiert, die von der Forschungsgesellschaft, der der Autor angehört, geleitet wurden, um dann durch eine Reihe organisierter Ausbildungskurse für Lehrmeisterinnen in der ganzen Industrie verbreitet zu werden. Diese Lehrmeisterinnen wurden von ihren Stammfirmen oder von ihren technischen Schulen ausgesucht, sie wurden ausgebildet und kehrten dann zu ihren Fabriken oder Schulen zurück, um ihre eigenen Ausbildungsstätten einzurichten.

Die Hauptschwierigkeiten dieser Organisation lagen nicht im Herausfinden erforlgreicher Ausbildungsverfahren, sondern in der Einrichtung und Unterhaltung von Ausbildungsstätten in der Industrie. Die dabei auftretenden Probleme und einige Massnahmen die zu ihrer Lösung angewandt wurden, werden beschrieben.

A THEORY OF THE ACQUISITION OF SPEED-SKILL*

By E. R. F. W. Crossman

Department of Psychology, Reading University, England

Recent researches are cited which suggest that the acquisition of manual speed-skill proceeds by a certain type of selective action. A formal theoretical model is developed, and its predictions compared with the experimental results. Certain complications of the theory, and conclusions from it are outlined, and the nature of the selective mechanism is discussed. Some implications for training are indicated.

§ 1. Introduction

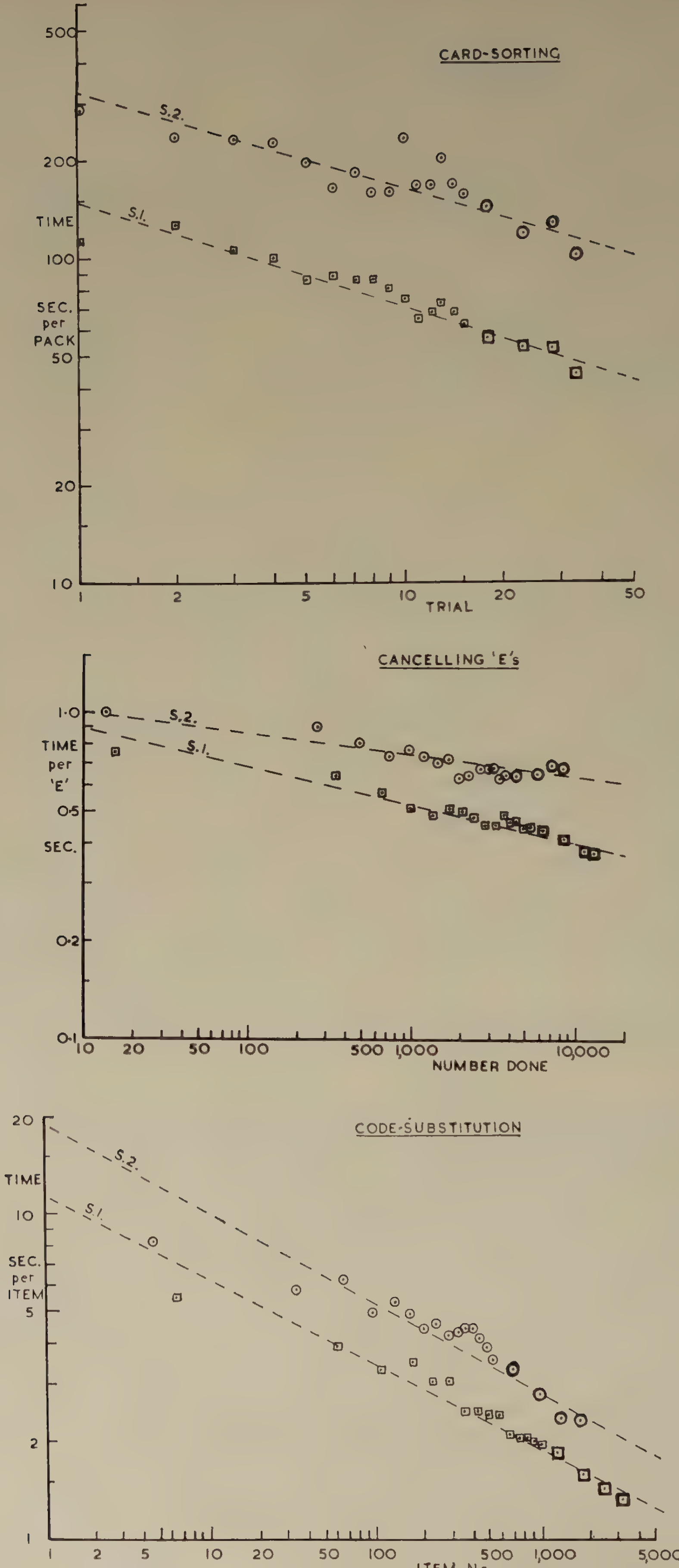
Training is an art which can be successfully practised with little or no scientific backing, but as in other fields, really reliable and reproducible results flow only from a sound basic theory. Since training serves to facilitate the natural process of acquiring skill by practice, the most important theoretical question is: how and why does a learner acquire skill in ordinary practice?

This paper is concerned with manual speed-skills and dexterities, a class of skills which is both common and important in industry today. Its aim is to put forward a theory of their acquisition suggested to the writer by the results of some recent experimental work carried out by Seymour at Birmingham University, and by de Jong at the Berenschot Bureau, Amsterdam. The theory stems essentially from the trial-and-error view of learning put forward by Thorndike more than fifty years ago (Hilgard 1948). Though this view has since been elaborated by many students of animal learning, and concepts of drive, reward, habit-strength, etc. introduced, no serious attempt seems to have been made to build up a quantitative account of the acquisition of skill from it. The writer has taken up its basic premise that a learner faced by a new task tries out various methods, retains the more successful ones and rejects the less successful ones, and has constructed from it a formal theoretical model to explain the experimental findings. While the model is presented here in a skeleton form, it agrees quite satisfactorily with experiment, and interesting new questions are raised.

§ 2. Skill and Learning

Recent researches on manual skill have been largely concerned with the *general* features of skilled performance; the importance of perceptual and central organizing activities, the temporal interlacing of receptor and effector actions, and the role of feedback or knowledge-of-results have all been stressed. But when studying industrial operations the writer has been struck by the highly *specific* nature of most skills. The expert's ability seems to lie rather in knowing exactly the right method to use in each situation that arises in the task, than in having superior coordination, acuity or timing. He can select the right source of signals to attend to, choose the right course of action, make precisely the right movements, and check the results by the most reliable means. In other

* The research was sponsored by the Medical Research Council, Department of Scientific and Industrial Research Joint Committee on Individual Efficiency in Industry, and financed from Counterpart Funds derived from United States Economic Aid.

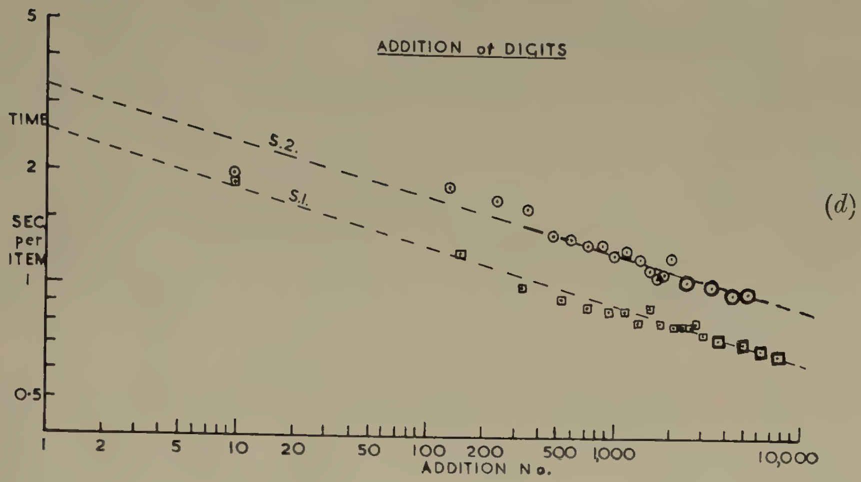


CARD-SORTING
TIME
SEC. per PACK
S.2.
S.1.
500
200
100
50
20
10
1
2
5
10
20
50
TRIAL
CANCELLING 'E's
TIME per 'E'
SEC.
S.2.
S.1.
1·0
0·5
0·2
0·1
10
20
50
100
500
1,000
10,000
NUMBER DONE
CODE-SUBSTITUTION
TIME
SEC. per ITEM
S.2.
S.1.
20
10
5
2
1
1
2
5
10
20
50
100
500
1,000
5,000

(a)

(b)

(c)



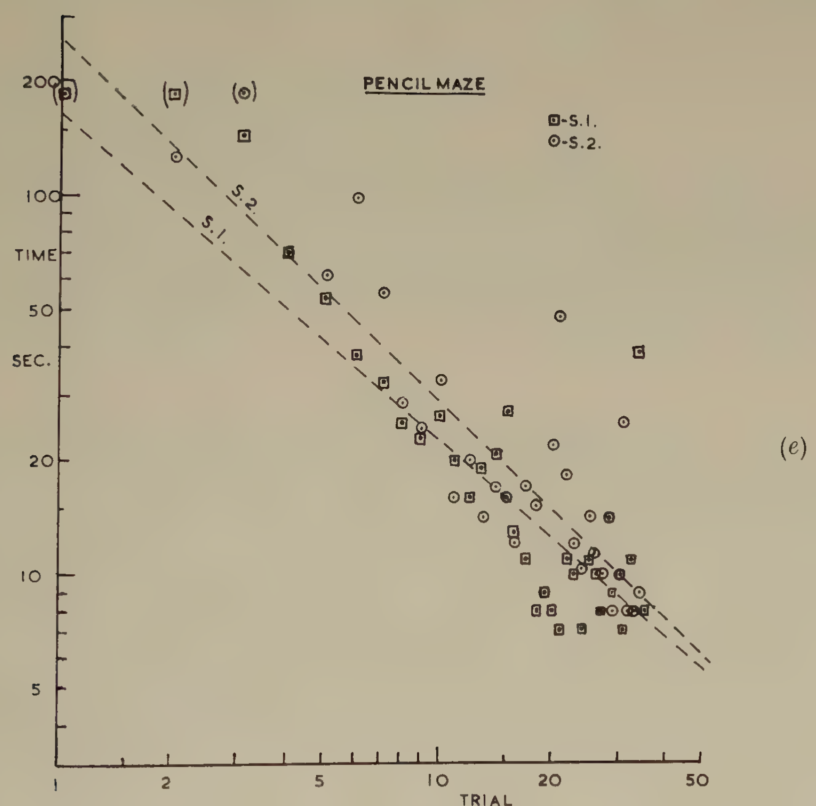


Figure 1. Learning curves on log–log scales for two subjects each on five tasks (data of Blackburn 1936).

words, his behaviour is closely 'adapted' to the situation in the same sense in which animals are said to become adapted to their environment by natural selection; he possesses only 'fit' behaviour-patterns.

For manual speed-skills, the operator's degree of adaptation is measured principally by his speed of performance, once success can be taken for granted. It increases gradually and continuously over long periods of practice, as many experimental learning curves have shown (Blackburn 1936). De Jong (1957) has recently put forward a rational equation which fits the results of several industrial studies. He finds that cycle-time plotted against cycle-number on log–log paper shows a linear decrease followed by an asymptotic approach to an 'incompressible' cycle-time; the relationship may be called 'de Jong's law'. De Jong has not provided statistical support for his argument, and some data are given here both to remedy the omission and by way of example.

2.1. *Practice and Speed in Five Simple Tasks*

Results given by Blackburn (1936) on card-sorting, cancelling *e*'s in nonsense French, adding digits, code-substitution, and maze-learning have been re-analysed. Figure 1 (*a* to *e*) shows the learning curves and Table 1 a statistical test of de Jong's law. The law clearly describes the data for the first four tasks well, but the fifth is doubtful.

2.2. *Long-period Improvement in Cigar-making*

A study was made of the speeds of production of several girls in the same shop, operating special-purpose cigar-making machines (Crossman 1956, Chapter 10). The job had a very short cycle, but considerable variation was experienced in the raw materials, and there was high 'perceptual load'. Figure 2 shows the weekly average cycle-time for operators of various lengths of service. Only after two years and about three million cycles does the curve depart appreciably from a straight line.

2.3. *Improvement of the Elements within a Motion-cycle*

Data provided by Seymour (1954) on learners operating a capstan-lathe have been re-plotted and are shown in Fig. 3. It is clear that the two elements obey de Jong's law as does the complete cycle.

The steady decrease in cycle-time shown by de Jong's law is accompanied by considerable variation from cycle to cycle. Studies of cycles and element times have shown quite clearly that the average does not decrease by a proportionate change in all times but by a change in frequency-distribution. Early in practice this is symmetrical; it becomes more and more skewed with practice, and finally J-shaped. Different elements show different initial distributions; very short ones (1–2 sec) tend to the rectangular or J-shaped, longer ones tend more and more to the Gaussian form. Figures 4 and 5 show typical results from an industrial assembly operation (15–20 sec cycle) and a laboratory assembly task (2 sec cycle). The scatter of element-times does not appear to be due to varying level of effort, and must presumably be attributed to variations of method. Unfortunately we have little direct evidence on the distribution of motion-patterns (but see de Montpellier 1935) and still less about that of perceptual activities. Lewis (1954) has, however, shown in car-driving that more skilled performers behave more consistently from occasion to occasion.

Table 1. A Statistical Test of de Jong's Law on Data given by Blackburn (1936) for Subjects Learning Five Simple Repetitive Tasks

Task	Subject	Regression coefficient b	Correlation coefficient r	Variance ratio F	Time for first trial	
					Predicted (sec)	Actual (sec)
Sorting 42 cards into individual compartments	1 2	−0·326 −0·300	−0·95 −0·91	1·40 1·35	149 322	111 279
Cancelling *e*'s in Nonsense French	1 2	−0·137 −0·064	−0·94 −0·76	4·67† 2·68*	14·1 11·5	2 (estimated) ,,
Substituting code symbols for letters	1 2	−0·261 −0·250	−0·99 −0·95	2·12 2·65*	11·4 16·1	10 (estimated) ,,
Adding pairs of digits	1 2	−0·147 −0·144	−0·97 −0·94	0·56 2·52*	2·47 3·34	3 (estimated) ,,
Tracing a pencil-maze blindfold	1 2	−0·949 −0·959	−0·84 −0·88	1·79 1·05	222 266	>180 >180

* Significant at 5 per cent level.
† Significant at 0·1 per cent level.

Notes: (1) Each subject performed 35 periods of about 180 sec each, on successive days.
(2) The logarithms (to base 10) of cycle-time have been correlated with the mean logarithm of the number of cycles performed up to and during each trial.
(3) The significance of the departure from linearity has been tested by Analysis of Variance, grouping the last 5 blocks of 5 readings together in order to estimate error. In each case the variance ratio F is based on 13 and 20 degrees of freedom.
(4) The times for the first trial are only known in two cases; in the others an estimate has been made.

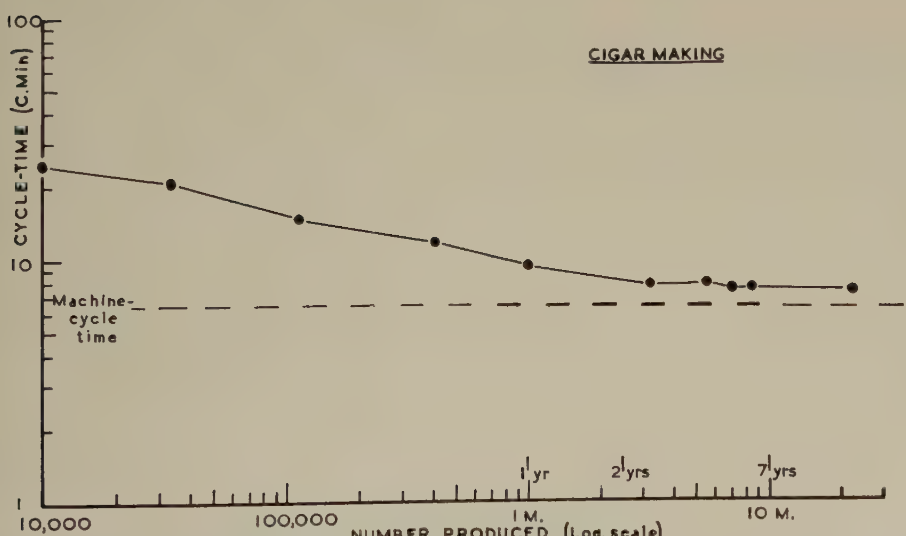


Figure 2. Practice and speed in cigar-making. Each point is the average cycle-time over one week's production for one operator. The ordinate is the total production by the operator since beginning work.

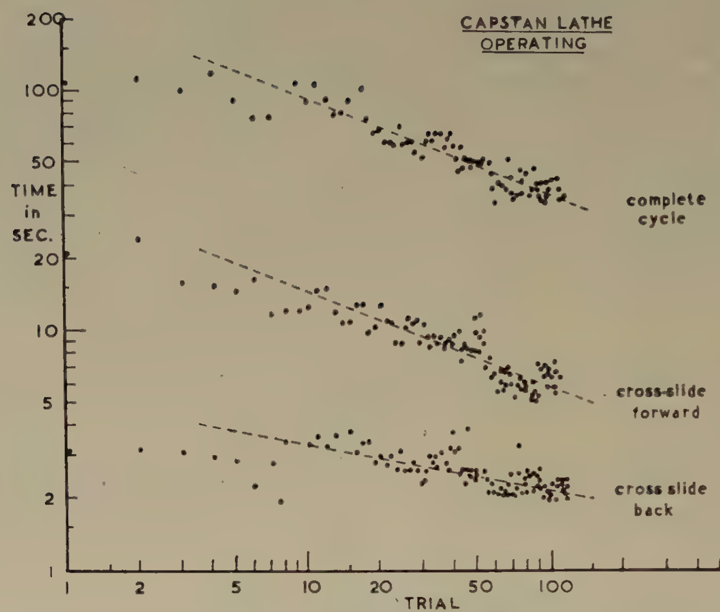


Figure 3. The effect of practice on element and cycle-times for a simulated capstan-lathe operation (data of Seymour 1954). The results of one subject are shown and each point represents one cycle of practice.

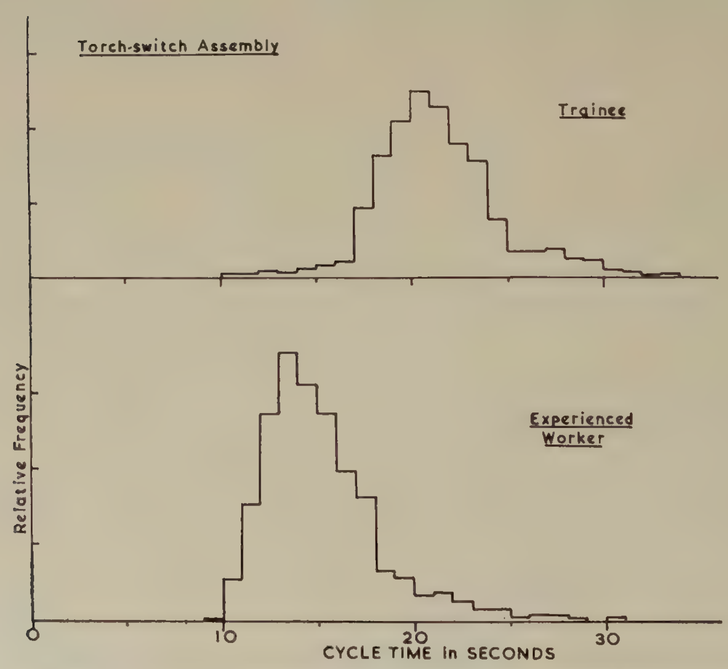


Figure 4. The distribution of cycle-times for a learner and an experienced worker at Torch-Switch Assembling (data of Dudley 1955).

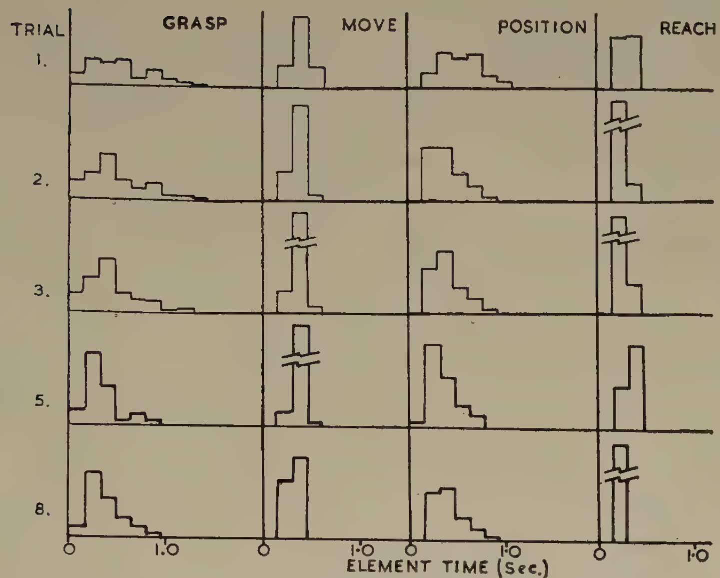


Figure 5. The distribution of element-times for a simple assembly operation (The Three-hole Connector). The four elements, reach, grasp, move, and position, are shown. Each histogram represents 100 cycles for one subject and there was no interpolated practice (data of Seymour 1956).

§ 3. A Theory of the Selective Process

These findings strongly suggest that practice exerts a selective effect on the operator's behaviour, favouring those patterns of action which are quickest at the expense of the others. In order to examine how this might work, a mathematical model of the selection process has been constructed, and will now be formally stated and discussed.

Let us consider an operator learning a repetitive task. For each trial or 'cycle' he will adopt some particular combination of sensory, perceptual, and motor activities, partly from deliberate choice, partly from habit, and partly by chance; these activities could, in principle at least, be completely described by an observer. In successive cycles he will use either the same or more or less different combinations. Let us call each such distinguishable action-pattern a 'Method' (M) and identify each by a subscript (e.g. M_1). The operator can be imagined to possess a repertoire or stock of r different methods, from which he picks one by chance for each cycle. The methods will each have a different 'habit-strength', availability or probability of use; let M_i occur with probability p_i where $\sum_{i=1}^{r} p_i = 1$. At the outset of practice the repertoire will normally include some wholly unsuccessful methods, but let us imagine that these have been eliminated, and that the repertoire includes only successful ones. From this point on, practice produces a steady decrease in the average cycle-time. At any one cycle, say the nth, the average cycle-time $T(n)$ is the time for all the Methods, M_i, weighted according to their probabilities p_i of occurring, i.e.

$$T(n) = \sum_{i=1}^{r} t_i \cdot p_i(n) \qquad \text{(1)}$$

where t_i = time taken by method M_i.

We assume that a selective effect takes place, increasing the availability of 'fit', i.e. quick methods, and reducing it for 'unfit', i.e. slow ones. To be precise, the speed of any method which happens to be used is measured in relation to the current average, and its probability of occurrence then changes in proportion to the result. Algebraically, let method M_i whenever it occurs have its future probability of being chosen increased by δp_i where

$$\delta p_i = -k(t_i - T(n)) \qquad \ldots\ldots\ldots \quad (2)$$

(where k is a small positive constant). Since M_i occurs on the average $p_i(n)$ times per cycle, the average change in its probability on one cycle is

$$p_i(n) \,.\, \delta p_i = -kp_i(n) \,.\, (t_i - T(n)) \qquad \ldots\ldots\ldots \quad (3)$$

and its probability for the next $(n+1)$th cycle is,

$$p_i(n+1) = (p_i(n) + \delta p_i) = p_i(n)[1 - k(t_i - T(n))]. \qquad \ldots\ldots \quad (4)$$

The average cycle-time for the next or $(n+1)$th cycle can now be calculated

$$T(n+1) = \sum_{i=1}^{r} p_i(n+1) \,.\, t_i = T(n) - k \text{ (variance of the } t_i). \qquad \ldots \quad (5)$$

(It is a convenient property of expression (4) that the sum of the $p_i(n+1)$ remains unity, hence no 'normalizing factor' is needed.)

Ideally the next step would be to express $T(n)$ as an explicit function of n, and plot the resulting learning curve; this can be done but the expression is

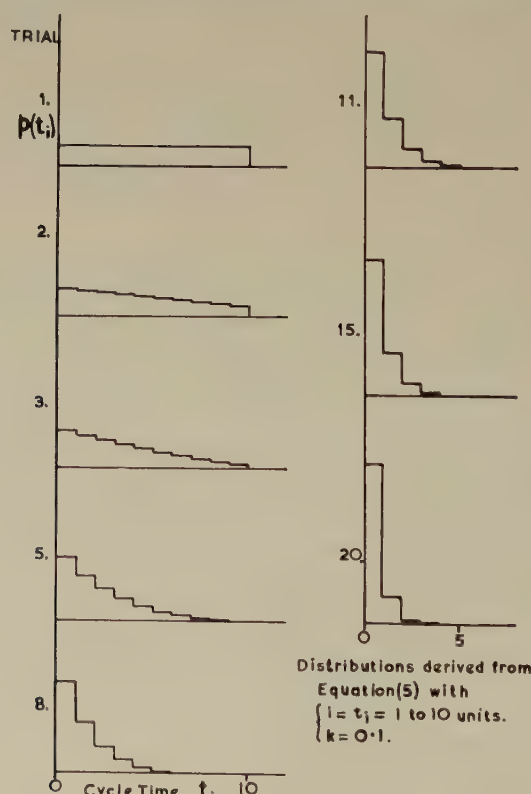


Figure 6. The distributions of cycle-times at successive cycles as predicted by the theoretical model (eqn. 5) for an imaginary task with 10 methods in the operators' repertoire ($k = 0{\cdot}1$).

complicated and involves high order moments of the initial distribution of the t_i. Instead, a learning curve has been computed numerically for an imaginary task where the learner starts with ten equiprobable methods, whose times are the integers 1 to 10, and practises with a selective constant $k=0{\cdot}1$. The distributions for the first 20 cycles are given in Table 2, and plotted in Figs. 6, 7 and 8.

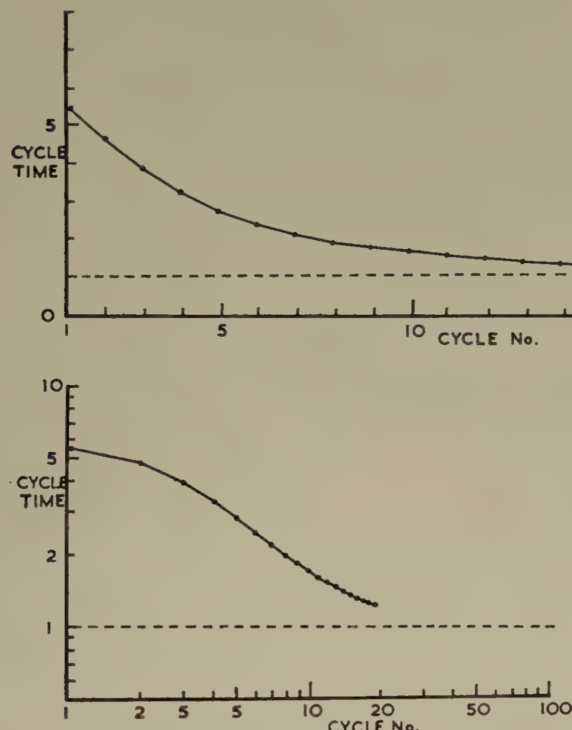


Figure 7. The learning-curve given by the theoretical model, plotted (A) on linear, (B) on double logarithmic coordinates.

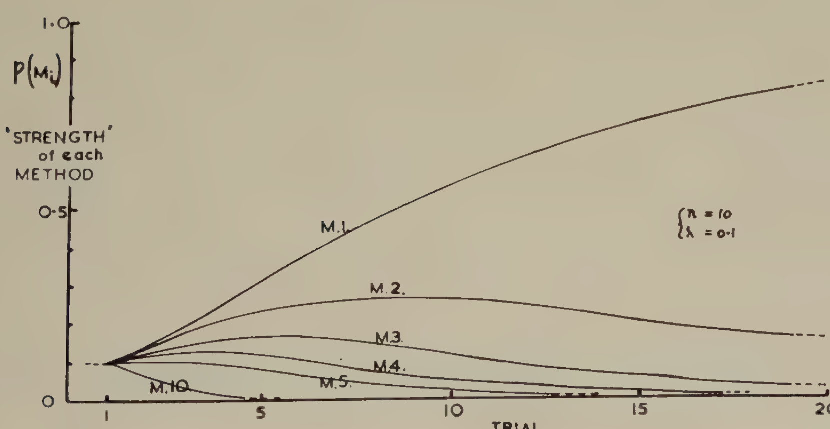


Figure 8. The change of availability of methods as practice proceeds according to the theoretical model eqn. 5.

Table 2. The Learning Performance of the Theoretical System

Time taken by method (units)	Probability of method							
	Cycle 1	2	3	5	8	11	15	20
1	0·1	0·145	0·198	0·315	0·476	0·607	0·733	0·839
2	,,	0·135	0·171	0·230	0·264	0·253	0·205	0·140
3	,,	0·125	0·146	0·164	0·140	0·097	0·050	0·020
4	,,	0·115	0·123	0·114	0·069	0·030	0·101	0·002
5	,,	0·105	0·102	0·075	0·031	0·010	0·002	—
6	,,	0·095	0·082	0·047	0·013	0·003	—	—
7	,,	0·085	0·065	0·028	0·005	—	—	—
8	,,	0·075	0·050	0·016	0·002	—	—	—
9	,,	0·065	0·037	0·008	—	—	—	—
10	0·1	0·055	0·026	0·003	—	—	—	—
Av. time	5·5	4·68	3·92	2·80	1·98	1·59	1·39	1·19

By comparing Fig. 1 with 7, and 5 with 6, the reader will see that the model does fit the experimental findings. There is only one clear discrepancy: the first few cycles of practice should be faster than de Jong's law suggests, and on this point there are indications (see e.g. Fig. 1) that the model gives a rather better fit to the experimental data than de Jong's formula. The theory could be tested more rigorously by applying it to the actual starting distribution for an element or cycle and testing the agreement between the predicted and actual learning-curves.

The curve of Fig. 8 shows that some individual methods may increase in strength at first, and only later decline towards zero; this recalls what does not seem to have been shown experimentally but can easily be seen in industrial practice, that certain methods may be learned at first, only to be discarded again as the average speed increases.

Several complications which arise in the real situation have been ignored, and a few of them will be briefly indicated:

1. It has been assumed that only one repertoire is being subjected to selection. In a real task there will be one for each different work-situation or sub-task that arises. Thus in reality several largely independent selection-processes must be going on at once.

2. Selection may act on elements rather than on the complete cycle. In order to find the distribution of cycle-times, one must then combine those of the element-times by *convolution*. The combined distribution may be quite unlike the separate ones (Fig. 9), and tends to be more and more Gaussian as the number combined increases (by the Central Limit theorem). The element-times for a long cycle must be highly skewed before the cycle-time is appreciably so.

3. The time for any one method may not be constant, but affected by chance variations in the work. This complicates but does not essentially change the picture.

4. The operator's repertoire may gain or lose methods during practice, by deliberate or chance invention, by instruction, or by forgetting. The rate of

learning is then affected in proportion as the variance of method-times is changed (eqn. 5), sometimes abruptly so.

5. The availability of methods may change for reasons other than selection. For instance, fatigue may be expected to reduce availability for any method which is used. The selection process would then be progressively distorted as any one practice period proceeds.

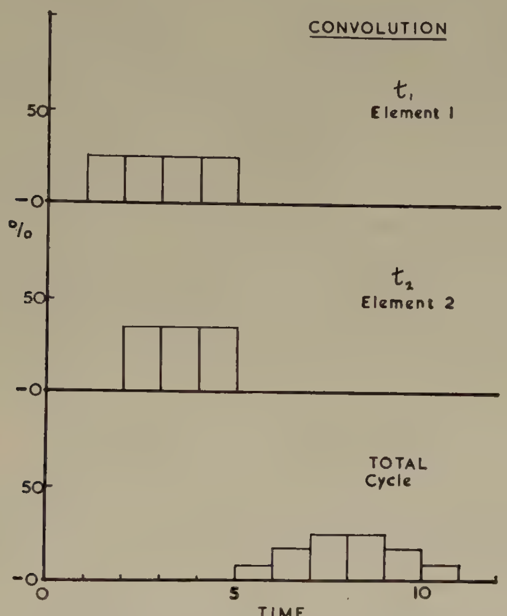


Figure 9. The frequency distributions of times for two elements combined by convolution to give the distribution of cycle-times.

Despite the complications, certain conclusions follow from the theory. First, the rate of learning for a sub-task will depend on the size of the learner's repertoire for it; on the variance within it, which in turn depends on the amount of previous selection; and on the selection pressure. Secondly, the overall learning period will increase steeply with the number of sub-tasks to be learned and with the initial variance of the repertoire for each; tasks whose sub-tasks are independent of each other will be more rapidly learned than those in which they interact. Third, transfer of skill from one task to another will take place where methods appropriate to one are also appropriate to the other, but the amount of transfer will depend on the *selectivity* that has been established rather than on the mere coincidence of methods.

The particular model given is only one out of a class of such models. The principle of selective processes in general can perhaps best be set out in a diagram (Fig. 10). The learner possesses a 'Pool of Methods', each with a certain strength, but no means of choosing particular ones; they differ in various respects, producing a variance in any given characteristic. The pool may have its variance increased or diminished as practice proceeds. The most important cause of reduction is selection in favour of methods more closely adapted to the work-situation. A parallel to this process is to be found in the genetical theory

of natural selection (Fisher 1930); here the genetic variance of a population is increased by mutation and reduced by natural selection. Unfortunately Fisher's mathematical treatment deals with two-factor (Mendelian) inheritance, and cannot be applied directly to this multifactor problem.

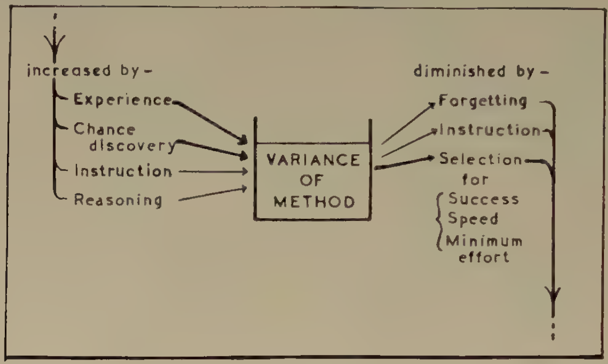


Figure 10. A diagrammatic representation of the selective process in the acquisition of skill.

§ 4. The Selective Mechanism

Although selection of methods for their relative speed has been postulated to account for the acquisition of speed-skill, it is not at all easy to see how the psychological and neural mechanisms could produce this result. At each trial the operator would have in some way to retain data about what method had been used, measure the time it took, and then alter its 'strength' in proportion. But judgment of short time-intervals is very inaccurate, and externally given knowledge-of-results such as the time taken for so many pieces, is not detailed enough to be effective. Instead of *time* the selective variable might well be *work* for if the operator exerts a constant level of effort, the work done to complete a cycle by any particular method would be proportional to its duration. If this were so, one would regard the gradual speed-up with practice as being secondary to the operator's pursuit of the minimum (physiological) 'cost' to himself, and the acquisition of speed-skill could be seen as an instance of the more general biological principle of 'Least Effort' (see e.g. Zipf 1949). Unfortunately there is even less indication that a mechanism exists for measuring physiological cost than one for measuring time.

A plausible case might be made for a mechanism based on the time-course of the decay of short-term memory. The method used for any given trial must necessarily be remembered to some extent, if any selective reinforcement is to take place at all, and it is obviously not permanently and perfectly remembered. If, as other experiments suggest, the memory of what has been done decays in a regular way with time, this might provide the necessary time-scale for the selective process. If the memory could be in some way 'fixed' by the successful completion of the element or cycle, then the sooner this happened, the more memory would remain to be fixed and the more chance there would be that the precise method would be recalled and repeated. Since most motion-elements seem to require a perceptual completion-signal of some kind, its arrival could cause the memory to be fixed.

§ 5. Implications for Training

If the acquisition of speed-skill depends primarily on a selective process, it follows that training should aim at deliberately strengthening the selection-pressure, while taking steps to ensure that the best 'methods' are in the learner's repertoire to be selected. The trainer must first know what is to be selected, i.e. what methods (both perceptual and motor) give fast performance; secondly, he must ensure that the learner can do them; and thirdly he must set up conditions in which they are consistently more successful than all others.

Verbal or visual instruction and demonstration are of use for putting the best methods into the repertoire, but for selection systematic practice under pressure for speed is probably the only effective way. Breaking down the task into elements increases selective efficiency, but the trainer must ensure that by so doing he does not find wrong methods being selected, that is ones that are optimum in the isolated element but not in the complete task. Those elements which have most variation of method need most selection and should be isolated; they are usually the ones which are highly specific to the particular job and so have not been selected by previous practice. Training for transfer, except where there are many identical elements, should presumably be aimed at giving the learner a good power of selection.

§ 6. Further Research

Studies of the distribution of methods rather than of times should show more clearly what is happening, and just how certain methods are selected; and tasks might be set up in which different sorts of selective pressure could be applied. Further mathematical analysis is also needed to make possible a proper comparison between theory and experiment.

On cite des recherches récentes qui donnent à croire que l'acquisition de l'habileté à vitesse manuelle a lieu par moyen d'un certain genre d'action selective. Un modèle formel théorétique est développé, et ses predictions sont rapportées aux resultats des expériences. De certaines complexités de la théorie, et des conclusions qu'on peut en déduire, sont décrites, et l'essence du mecanisme de sélection est discutée. Quelques implications pour l'entraînement sont indiquées.

Es wird über neuere Forschungen berichtet, die annehmen lassen, dass die Erwerbung manueller Geschwindigkeits-Geschicklichkeit durch eine Art selektiver Handlung erfolgt. Dafür wurde ein theoretisches formales Modell entwickelt und die sich daraus ergebenden Voraussagen mit den experimentellen Resultaten verglichen. Gewisse Komplikationen der Theorie und Schlüsse, die sich daraus ziehen lassen, werden besprochen und die Natur des selektiven Mechanismus diskutiert. Einige Folgerungen, die sich daraus für das Anlernen ergeben, werden aufgezeigt.

References

Blackburn, J. M., 1936, Acquisition of skill; an analysis of learning curves, *I.H.R.B. Report*, No. 73.

Crossman, E. R. F. W., 1956, The measurement of perceptual load in manual operations. Unpublished Ph.D. Thesis, Birmingham University.

Dudley, N. A., 1955, Output patterns in repetitive tasks. Unpublished Ph.D. Thesis, Birmingham University.

Fisher, R. A., 1930, *The Genetical Theory of Natural Selection* (Oxford: University Press).

Hilgard, E. R., 1948, *Theories of Learning* (New York: Appleton-Century), p. 409.

de Jong, J. R., 1957, The effects of increasing skill on cycle-time and its consequences for time-standards. *Ergonomics*, **1**, 51–60.

Lewis, R. E. F., 1954, Consistency and car-driving skill. *Brit. J. industr. Med.*, **13**, 131–141.
de Montpellier, G., 1935, *Les Alterations Morphologiques des Mouvements Rapides* (Louvain: Eds. Inst. Sup. Philos.), p. 251.
Seymour, W. D., 1954, Experiments on the acquisition of industrial skills, Parts I, II, and III. *Occup. Psychol.*, **28**, 77–89; **29**, 82–96; **30**, 94–104; 1956 (personal communication).
Zipf, G. K., 1949, *Human behaviour and the Principle of Least Effort* (New York: Addison Wesley Press).

PRACTICE AND KNACK
SOME COMMENTS ON LEARNING AND TRAINING IN INDUSTRY

By Isabel Blain

National Institute of Industrial Psychology

Learning a task differs psychologically from doing it once skill is acquired. Industrial training should focus on actual learning processes and on fostering the desire to learn.

Learning may be helped by directing attention to kinaesthetic experience, which in turn can convey more meaning if irrelevant differences in machine adjustments and work-place layouts are minimized.

Learning depends on identification of good responses. Knowledge of success achieved tends to create a desire for more success. The skill of instructors in using these principles, with learners who vary in rate of progress, is likely to be an important influence in the effectiveness of industrial training.

§ 1. Introduction

The following remarks refer mainly to what industry would call semi-skilled work, where it may be alleged that a *knack* must be learned or that 'you need a lot of practice to get up speed'. Individually, perhaps, of little importance, in the aggregate these jobs employ many thousands of workers ; moreover, since in this range of occupations people change jobs with relative frequency, means of reducing learning time may be expected to yield disproportionately high returns in productivity.

The activities and arrangements which we call training have as their object the acquisition of skill by the learner. It must be recognized that while a man may acquire skill, an instructor cannot, strictly speaking, impart it. All that training (in its transitive sense) can do is (1) to facilitate the actual processes of learning and (2) to encourage and foster a person's desire to learn and accordingly his effort. From this it follows that those who undertake to train others need to appreciate what is involved in *learning* a task as distinct from doing it. There can be little doubt that, from the psychological viewpoint, learning is a very different experience from doing a job after the skill has been acquired.

Recent researches have furnished invaluable physiological or quasi-mechanistic explanations of the nature of motor-learning processes. Other experimental work has clearly shown the value, in some circumstances, of the long established method of isolating certain parts of a task for special practice. To the identification of such difficult parts as 'perceptually loaded' we might add "those that have movements which are unfamiliar, require a high degree of control, or have results that in some way run counter to expectations". The residual problem for industrial trainers, however, is how to utilize these formulations to assist learning, that is, to enable learners to achieve the greatest accuracy and adaptability of movement in the shortest time.

§ 2. Facilitating Learning

In the process of learning any manipulative job, muscular responses are subject to increasing precision of control, to which both touch and kinaesthesis

contribute. A kinaesthetic component is inherent in the stimulus pattern of any work where a tool is applied or material manipulated ; it may be the crucial factor in modulating muscular control, and it is important to realize that though it may be inferred, it cannot with certainty be detected by an observer ; it can only be experienced. Descriptions of one man's experience, nevertheless, can sometimes be used to direct a learner's attention to similar features of his own experience, thus enabling him the sooner to produce a good response and get the ' feel ' which will guide him in the future. Splicing two ends of wire—an essential operation in certain types of wire weaving—is an example. It had sometimes happened that women could not do this part of the job after as long as eight weeks, although it was a process which had to be carried out many times each day. But once we had discovered the ' feel ', we could put into words new aspects of a method which previously was only shown and superficially described. After that a join was always achieved at the first try, and a good join within a very few days. This is not to contradict Belbin's (1958) observation that experienced operatives' own verbalizations may be useless to learners, and that completely non-verbal training methods may in some circumstances be successful. The important point is the heightening of kinaesthetic awareness, and certain kinds of augmented feedback described by other contributors to this symposium have precisely that purpose.

If we grant that proprioceptive signals may be crucial elements in the total system of information presented by an industrial task, and that learning to ' read ' information contained in these signals may be an important stage in acquiring skill, then it follows that the time needed to acquire a given level of skill may be related to the time necessary for learning to identify the significant signals, or cues, from the multiplicity of those presented. If means can be found to reduce the irrelevant variability in the proprioceptive signals that a worker receives, it may be expected that he will the sooner discover the standard pattern and notice deviations which deserve attention.

For example, if a signal pattern is repeated frequently without variation, its meaning will be more quickly learned than if each presentation is a little different from the one before ; and if it is repeated with only small variations learning is likely to be quicker than if the variations are marked. Music offers a clear illustration ; it is easier to memorize a simple tune, with an unvaried melodic line, than to discover a similar sequence of notes in a work by, say, Bach, where it also recurs frequently but so surrounded by other notes, so varied by compression or extension of tempo, and so on, that an unpractised listener may be unaware of the recurrent theme. But if you play him the theme alone from the Bach work, and after a few simple repetitions play, complete with the variations, the composition in which it occurs, then even the inexpert listener is more likely to identify relatively soon at least some of the recurrent, even if varied, repetitions.

Repeated presentation of a stimulus system consisting of musical sounds is technically easy, but where the important cues are proprioceptive, that is, arising in the learner's own musculature, the problem of identification is more difficult. I want however to suggest that we do have means, often neglected, of assisting learners in this matter.

My first suggestion is that one way of reducing irrelevant variations in the signals received by workers who use tools or operate machines would be to

maintain these tools and machines in a relatively constant state of adjustment. The reluctance which even experienced workers sometimes express towards operating any machine other than what they consider their ' own ' may be due in part to small differences in the adjustment of controls so that they are, for instance, stiffer or slacker to move and thus present unfamiliar proprioceptive signals, or familiar signals carrying new meanings that have to be learned before the machine can be operated with normal competence. The same thing may be noticed in driving a car—when you drive a new one, or one belonging to a friend, even if the model is the same as your own, you have to get the ' feel ' of the unfamiliar controls before you are quite at ease with them.

The analogy of driving may take us a step further. If, when *learning* to drive, you practise on cars of different makes, where not only the adjustment but the shape and particularly the position of the controls may differ, you are presented with stimulus systems which are not only complex but which vary from car to car. Similarly, the industrial learner whose tools and components are sometimes in one place and sometimes in another is presented with greater variation in signals than the learner whose job layout is standard and whose working method is prescribed.

My second point, therefore, is that needless variability of signals can be minimized by attention to layout, so that any variation which is experienced will carry more information than in the case where layout is casual or haphazard. One characteristic of skilled performance of a task, often thought to result only from long practice, is the quick discrimination of any case where a component in assembly work, or the result, or even the feeling, of a habitual movement, differs from ' normal '. It seems certain that this discrimination, essential for the prevention of error, contributes at least as much to the goal of " high output of good quality " as does sheer speed of movement ; accordingly it should receive due attention in the design of training programmes.

The inference for trainers is a new emphasis on the importance of orderliness. Where formerly it has been thought that motion study encouraged the development of speed by eliminating needless movements, it seems likely that it also assists learning by ensuring that kinaesthetic signals carry maximum information for the learner.

Industrial learning can take place only as correct responses or discriminations are identified and attempts made to repeat them. Until a learner can be relied upon to make correct responses repeatedly he is not proficient. Achievement of this stage can be expedited not only by various means that shorten the path to the first success but also by ensuring that the first and early subsequent successes are notified to the learner without delay. Only thus can he develop certain knowledge not only of the feel of the correct movements, but also of the look or other indication of correctness of the end product. While mechanical devices may often assist in this respect, the contribution that can be made to such learning by a good instructor is invaluable.

§ 3. Instructor's Rôle in Fostering the Desire to Learn

A desire to learn, in whatever degree and for whatever reason, is essential for any learning that is to be either rapid or thorough. Study, from a psychological angle, of the behaviour and progress of learners in industry suggests

that they normally have this desire (or at the very least the wish to avoid failure) when they come fresh to a task, but it may not survive the discouragement of apparently slow progress or neglect. In this case effort flags, progress is retarded, relationships deteriorate as management costs rise, and patience perhaps diminishes ; and if the learner leaves at this stage, as so often happens, there must be faced again the trouble and cost of replacement and starting the whole cycle once more. Hence it can be seen that to encourage and foster the desire to learn are important functions, reasonably attributed to training, and largely dependent upon instructors, whether they be officially appointed or not.

The design of training schemes can embody potentially motivating features. For instance, it is often possible to arrange practice and use records of progress in such a way that learners *can* experience some measure of success early and often ; and to experience success is likely to breed the desire for more, which doubtless encourages the effort necessary for advance. But for the efficient application of any programme the instructor skilled in teaching is indispensable. For example, people learn at different rates ; as practice, if continued beyond a certain point, may be harmful rather than helpful, the length of practice periods may require modifying to suit learners' needs. Competition and other devices such as setting targets of accomplishment appear to have value—again where they offer some prospect of experiencing success ; but they may be ineffective and even damaging if achievement seems out of reach.

Thus it can be seen that while there lie to hand many means of fostering and reinforcing learners' effort, and while this aspect of training clearly merits attention, the ability of instructors to appreciate problems of learning in general and of individual learners in particular, and to modify their own words and actions accordingly, is likely to remain an important influence in the success of industrial training.

L'action d'apprendre une tâche est psychologiquement différente de celle de l'exécuter une fois apprise. L'entraînement industriel devrait s'appliquer aux procédés de l'étude, et encourager le désir d'apprendre. On peut aider à apprendre en dirigeant l'attention à l'expérience kinésthetique, ce qui, à son tour, peut gagner de signification si les différences sans importance d'ajustements de machines et de dessins d'atelier sont réduites au minimum. Pour apprendre on dépend de la faculté d'identifier les réponses correctes. La conscience d'avoir réussi mène au désir de réussir d'avantage. L'adresse des instructeurs à employer ces principes avec des élèves qui ne font pas tous le meme sera progrès sans doute une influence considérable pour l'efficacité de l'entraînement industriel.

Die Erlernung einer Aufgabe unterscheidet sich psychologisch von ihrer Ausführung nach erlangter Geschicklichkeit. Das Anlernen in der Industrie sollte sich auf den eigentlichen Lernprozess und auf die Förderung des Wunsches, zu lernen, konzentrieren. Das Lernen könnte dadurch unterstützt werden, dass die Aufmerksamkeit auf kinästhetische Erfahrungen gelenkt wird. Das gilt besonders, wenn Unterschiede in der Maschinen-Anordnung und der Arbeitsplatz-Gestaltung möglichst gering gehalten werden.

Lernen hängt davon ab, ob man seine Fortschritte erkennt. Erfolg schafft den Wunsch nach mehr Erfolg. Die Geschicklichkeit der Lehrmeister, diese Prinzipien bei mit unterschiedlichen Fortschritten Lernenden anzuwenden, ist wahrscheinlich ein bedeutender Faktor in der Wirksamkeit industrieller Ausbildung.

Reference

Belbin, E., 1958, Methods of training older workers. *Ergonomics*, **1**, pp. 207–221.

THE OPERATOR AS A SELF-REGULATING SYSTEM
A Factory Experiment

By S. David M. King

Organization & Training (Consultants) Limited, 19 Bolton Street, London, W.1

In industry it is not unusual for the performance of ex-trainees to fall after entering the production department. During training the trainee is treated, from a cybernetic viewpoint, as a self-regulating system. In the normal production department, however, the operator finds his role restricted to performing tasks, the control of which is largely vested in the supervisor. In the experiment described here the setting up of a training department was combined with the re-organization of the associated production department. This re-organization provided the conditions in which the operators, after re-training, could continue to act as self-regulating systems. It coincided with a marked improvement in performance.

§ 1. Introduction

It may seem a far cry to speak of learning and training in cybernetic terms, yet there is at least one important sense in which this can be done significantly. Training procedures are designed to provide structured information to the 'input' of the individual, on the requirements of the tasks and on the errors made in performance. The process of learning is likely to be quickened if this information is transmitted directly from the environment to the individual, rather than through the filter of another individual as in verbal instructions from an instructor; that is to say, learning will be assisted where the training exercises are self-administering. It is also probable that the individual will learn more quickly when he can regulate the input flow of information to the pace at which he can assimilate it; that is, when he can set his own targets for the attainment of any particular aspect of the total task. All this implies that the operator will learn to perform a given task more quickly when conditions are provided which assume he will act as a *self-regulating system*.

Many training schemes are successful in providing the conditions in which trainees learn their jobs quickly. But it frequently happens that the performance of successful trainees drops on entering the production shop (King 1948). An analysis of the organization in the production shop will almost certainly show that the operators' roles no longer permit the persons filling them to act as self-regulating systems (Argyris 1957).

In the production department a supervisor is normally placed 'in charge' of the working group of operators. The working group does not relate directly to its task in all respects. Much information about the task is filtered through the supervisor to the operators. The supervisor will transmit, for example, instructions regarding the requirements of the task and corrections on its performance. Thus the working group performs the role of the 'activity' component of an open system, while the supervisor acts chiefly as the 'control' component. This may be termed a 'split system' organization and it is shown schematically in Fig. 1.

Where relationships between the supervisor and the working group are 'good', it can be said that the activity and control components in the 'split

system ' organization are well-enough matched to constitute an integrated system. The whole system responds to common frames of reference and a minimal distortion of information occurs. Nevertheless, neither the supervisor nor the operators are acting as self-regulating systems, and in consequence it may be suggested that a considerable waste of human resources takes place.

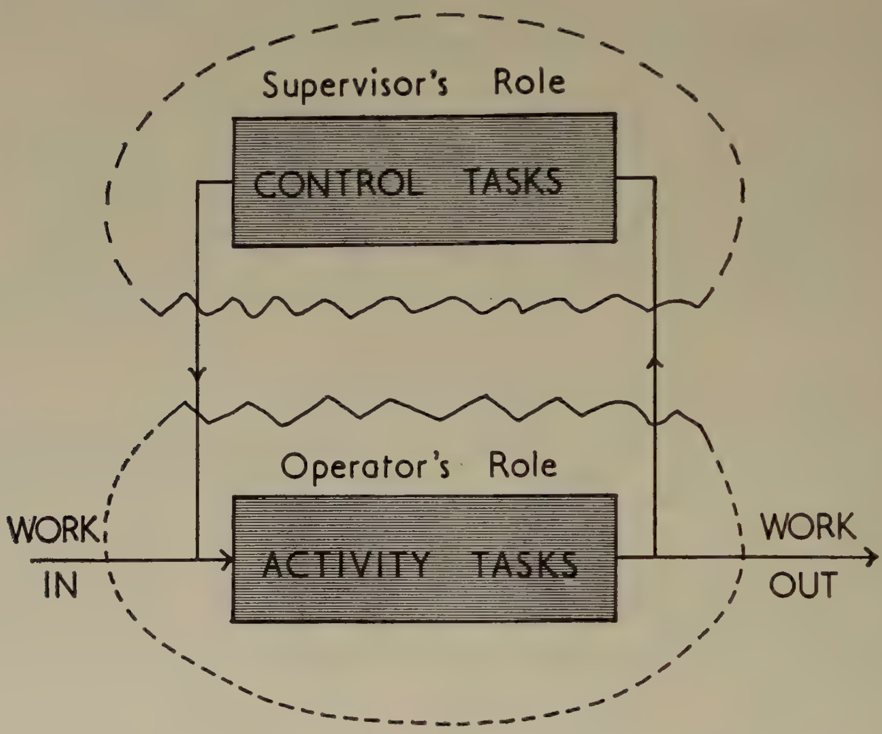


Figure 1. A simplified diagram of the separation of ' control ' and ' activity ' tasks between supervisor and operator in a conventional production shop organization. The operator is concerned chiefly with activity, while immediate control of his performance is largely vested in the supervisor or ' over-looker '. Since self-regulation demands that both control and activity components be built into the same system (or role) this may be termed ' split system ' organization.

' Bad ' relationships between the supervisor and the operators may be described as an open system with *unmatched* activity and control components. The system indeed effectively divides into two sub-systems, each with its own individual characteristics. For it is the working group's own frame of reference (rather than the firm's) which regulates its behaviour, sets the limits to ' what is done ' and ' what is not done ' and gives rise to phenomena such as those described in the Hawthorne experiments.

Recent experiments carried out by Rice (1958) on work re-organization in an Indian textile mill indicate some effects of a scheme deliberately designed to give working groups increased control of their own activities. The experiment to be described here had a similar aim—to allow the operator to act as a self-regulating system as indicated in Fig. 2. Operators in a mass-production assembly process were re-trained in the skills of manual operations. During their period of re-training they were also taught the skills and techniques of

controlling their own work organization. Their roles were enlarged on management authorization to include the tasks concerned not only with machine operation, but with such organizational procedures as division of work, assignment of roles to operations, lay-out of machines, work methods and work measurement, and finally the setting of performance targets. The results consequent upon this re-organization showed an increase in productivity of over 60 per cent. Satisfaction in work improved noticeably but was not subject to measurement. Although the experiment was admittedly not well controlled, the results obtained may give some indication of the human potential awaiting development, and certainly suggest the need for more experimentation of this kind.

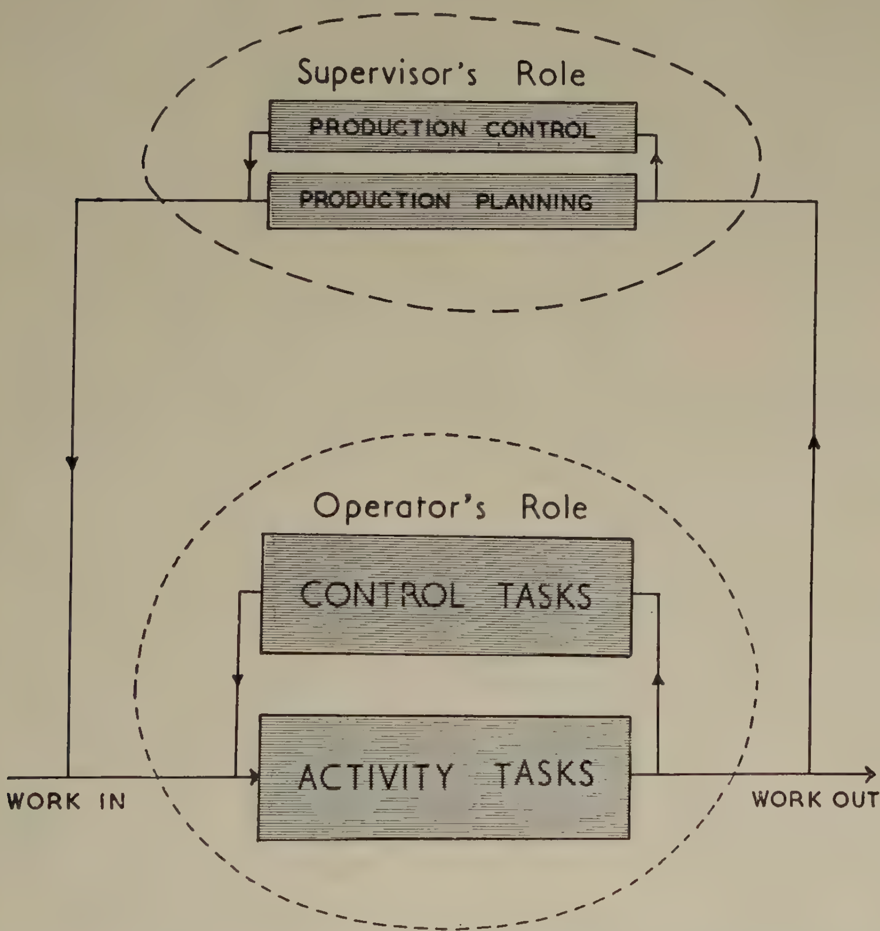


Figure 2. A representation of an operator's role when designed as a self-regulating system. Here the operator has authority to control his own activity within certain agreed limits. The supervisor, freed from detailed control tasks, can concentrate on longer term production planning and control (Singleton 1958). The ' split system ' of Figure 1 has been replaced by two interacting self-regulating systems, one ' governing ' the other.

§ 2. Background of the Experiment

The management of an old-established Norwegian family business decided to build a new factory in a country district, some twenty miles away from the

town in which the parent factory was situated. While the new factory was being constructed, a group of 22 girls (2 cutters, 16 machinists, 1 presser and 3 examiners) was engaged to carry out the cutting, sewing, pressing, inspecting and packing operations in the manufacture of children's pyjamas. These operators worked in a hut alongside the new building site. A middle-aged forewoman carried local responsibility for production, and a mechanic was engaged to service the machines.

A year after the establishment of the branch factory, the management invited a consultant to set up a training scheme for the operators working there, although the performance of these operators was said by management to compare well with that of the town operators. By providing re-training facilities, management aimed to raise the productivity of the new factory.

The mechanic was appointed to the position of training supervisor, and a small builder's hut was chosen as the training centre. The scheme was explained individually to each operator, and a general meeting was then held to discuss the need for re-training. Two girls were recommended by the supervisor as being potential instructors. After further interview they were offered the opportunity of taking the re-training course first, and they accepted this not only with interest but with the support and sanction of the other operators.

§ 3. Training in Manual Skill

The re-training programme was based on an analysis of the requirements of the operator's role. The skilled operator and her machine may together be viewed as forming a ' paired ' open system, the machine acting mainly as an

Role requirements	Stages of programme
1. To develop fine sensory discrimination particularly in visual, tactile and kinaesthetic components, and to learn fine movements especially in the fingers, hands, arms, legs and feet	1. ' Basic Skills '
2. To learn the ' feel ' of the cloth	2. ' Handling the material '
3. To operate and service the machine	3. ' Handling the machine '
4. To adapt the cloth to the operation of the machine so that different kinds of seam are sewn	4. ' Basic elements of the job '
5. To translate the instructions for sewing a particular garment into the appropriate inspection and movement pattern at given standards of quality and at the required speed	5. ' The single operation '
6. To maintain performance at the required speed and quality over the working day	6. ' Build up of performance '

amplification stage to the operator's activity. Into the input of this system is fed knitted cloth and instructions as to how the cloth is to be handled. If the instructions are correctly interpreted and realized, a correctly sewn garment appears at the output stage. The role therefore makes certain basic requirements of the person, and these are shown in simplified form in the table alongside the stages of the re-training programme.

The actual method of training adopted was designed to incorporate the following principles:

' Built-in ' instructions

The more the instructions are implicit in the task and its targets, the less will the operator have to translate them from one channel to another; e.g. from verbal to visual channels. Learning appears to be facilitated when instructions are ' built-into ' the tasks (Belbin *et al.* 1957).

' Built-in ' feedback

It is well known that knowledge of results of performance enables errors to be corrected and thus facilitates learning. Where knowledge of results is built into the tasks, the operator has neither to wait for instructions nor to translate such instructions into the ' activity ' channels. Most of the exercises (e.g. in handling the material) had time and accuracy targets built into them. Errors were self-evident and thus automatically fed back to the operator, without the need for intervention by an instructor.

The operator as a limited capacity channel

Another assumption was that the operator can only accept a limited amount of information at any one time. The daily training schedules were therefore designed to enable the operator to assimilate the task in easily ' digestible ' units. Where an operator failed to reach a target in normal time, the task would be analysed to find where the over-load was occurring (Kay 1957).

Choice of appropriate method

It has been suggested by Crossman (1959) that the " acquisition of skill proceeds by the unconscious selection of appropriate methods " and a rejection of less useful ones for any given task. It is then the function of training procedures to provide the learner with guides to a more rapid selection of the optimum methods. In these procedures achievement of the target would indicate to the operator that she had selected an appropriate method in relation to the required performance. She was not instructed in any ' best ' method. Instead she was assisted by the instructor in discovering the method most appropriate to her own way of working.

Role of the instructor

Since most of the training exercises were largely self-administering, the role of the instructor developed into one of providing technical resources (as in the selection of methods) and of creating a blame-free atmosphere in which the trainees could learn from their mistakes without ' losing face '.

Maintaining high performance

Having learnt the most appropriate methods for the single operation, the operator still has to adapt herself to long periods of repetitive work at a high

level of performance, without undue fatigue. The training procedures allowed the operator to adapt herself gradually to longer production runs through progressive loading.

§ 4. Training in Work Organization

In the training centre the training supervisor was taught not only the procedures for training in manual skills (Seymour 1954), but also some principles of work study, work organization and leadership. He in turn passed on to the first two operators all that he himself had been taught. After about three weeks both these operators became instructors. During the subsequent weeks 12 more operators entered the training centre in groups of three; each group being instructed for about three weeks by one instructor who then followed them back into the production department while the other instructor trained the next group in the training centre.

The manual skills training was amplified by a series of informal discussions and demonstrations on the organization of work. During the course of these sessions the garment was broken down into a number of seams. Having agreed on the sewing methods the operators timed themselves on each seam over a series of runs of 12 garments. The times for each seam over a run of 12 garments were then graphed by the operators to portray a learning curve. As each curve flattened out, a ' good ' average time was agreed with the operators as being a suitable target time for that seam. (It should be noted that the operators had already learnt to set their own targets on a ' good ' average time in the training exercises.) The optimum order in which the seams should be sewn to give a balanced work flow was then suggested by the operators in consultation with the instructors. Two seams were allocated to each operator, making a total of six operators to a team as compared with the old organization of five and a half operators (one girl working part-time) practised in the production department. It is, of course, the longest operation time taken by any one operator which determines the speed of production. According to the times taken in the training centre, the longest operation time under the old organization was 8 min 20 sec. This time was reduced with the new organization to 6 min 30 sec. While this is a normal work-study procedure, it is significant in the present context because it was carried out by the operators themselves.

During the course each operator specialized in one type of machine; she also learnt to operate the other machine, however, and in fact had some training in every operation on the garment. When high production was required, the operators performed the operations on which they had specialized. When circumstances, such as a shortage of work, prevented a high output, the operators interchanged their roles so that they could get more practice on the less familiar operations. Re-arrangements of this kind did much to even out the considerable difference between the highest and lowest average operation times. This ' multiple role ' training arose spontaneously out of the discussion on work organization (Trist and Bamforth 1951).

§ 5. Installing a Revised Method of Production

By the time that the first six operators had been through the training centre, it was clear that a substantial increase in productivity might be achieved

if conditions in the production shop were favourable. This was characterized, however, by 'old fashioned' supervision and by the original form of work organization. Accordingly the managing director decided that a re-organization should take place, and the matter was discussed with the fore-woman, who was given several weeks' paid leave and offered the opportunity of returning as an ordinary machinist. She accepted this and came back after only two weeks. She applied to go through the re-training course and later joined the second team with noticeable contentment. The training supervisor was appointed foreman, and a trainee mechanic was engaged to assist with machine repairs.

The managing director then gave formal authorization that any changes in work organization proposed by the new foreman and the working group should be carried out. A few days later, after full discussion, the first six operators re-arranged their work organization, agreed on fatigue and contingency allowances and designed their own layout of machines. The layout chosen utilized 75 per cent of the floor space originally used, and provided the conditions for a more compact social group. Quality standards had already been agreed with the operators during training, and it only remained for the first group to set their production target and confirm it with the foreman.

The rapid decentralization of decision-making caused some confusion immediately following the departure of the forewoman, because everybody had been dependent on her for detailed decisions. This was remedied by the informal establishment of local policies which were discussed and agreed with the senior operators and the teams of machinists, and which acted as frames of reference within the limits of which local decisions could be taken. The foreman's role became much more of a technical advisory and coordinating function, in so far as he was called to deal with problems which were either beyond the operators' technical experience, or were concerned with relations between groups. Information was 'situation centred' rather than 'person centred', and it flowed freely up as well as down the executive system. The mechanism for the control of activity appeared to reside within the working group and to depend upon agreed rather than applied standards of discipline. The operators apparently enjoyed this pattern of management and their performance might be taken as an expression of increased satisfaction, but there is no clear evidence to confirm that this was the case.

Records for the four months preceding the introduction of training in the branch factory showed a consistent average production by a group of $5\frac{1}{2}$ operators, of 33 dozen garments per $8\frac{1}{2}$ hour day. This equalled a daily rate of productivity of 6 dozen garments per operator. In the weeks following re-training and re-organization, the first group of 6 operators set their target at 60 dozen garments per $8\frac{1}{2}$ hour day, and achieved this still on time rates, before the management had completed preparations for a simple financial incentive system based on a group bonus. The daily rate of productivity thus rose to 10 dozen garments per operator.

This average level of productivity was maintained by both teams until events occurring in the environmental systems of the firm and industry caused serious disturbances in the flow of work to the operators. These events compelled management to disband the working groups for a time, and return to more individual working. While it was not possible to obtain accurate figures

following the disbandment, the information available suggested that productivity returned to approximately the original level.

§ 6. The Changed Role of Supervision

The role of supervision changed distinctly following the re-organization. The forewoman had been appointed to her position because she was older and more experienced than most of the other operators. She was given little or no training in the tasks of management. She received instructions from above and issued detailed instructions to her subordinates. For the most part, information flowed only one way; that is, down the executive system. She delegated a minimum of responsibility and authority to her subordinates, taking decisions on almost all the details of production management in the branch factory. She was consequently very busy. Arguments were frequent and were nearly always ' person centred ' in content. She exercised a strict discipline over her subordinates; those who conformed easily were favoured, and those who did not conform became scapegoats. The alacrity with which the forewoman later returned to the job of machinist indicated that she was not very happy in this role of supervision, and this was confirmed in the discussions with her.

On taking up his appointment as foreman, the former training supervisor operated his role in a noticeably different manner. He had firstly received some training for the job in his role of training supervisor. On his new appointment, the tasks for which he carried responsibility were clarified with him: that is to say, his perception of his new role was structured. He then proceeded to delegate many of the decisions formerly taken by his predecessor to his chief subordinates, and spent some time clarifying their tasks and training them in their responsibilities. The standards of performance expected of them were ' built into ' their roles. Where mistakes occurred, action was taken to improve the situation and avoid their recurrence rather than with a view to laying the blame.

The writer is indebted to the members of the firm and to G. H. Ladhams, whose collaboration made this study possible.

Dans l'industrie on voit souvent que le rendement des opérateurs qui ont subi l'entraînement baisse apres qu'ils sont entrés au département de production. Pendant l'entraînement l'élève à entraîner est traité, du point de vue cybernétique, comme système autorégulateur. Dans le département normal de production au contraire l'opérateur trouve que son rôle se restreint à l'exécution de tâches dont le contrôle réside dans les mains du surveillant. Dans l'expérience ici décrite l'institution d'un département d'entraînement fut associée à la réorganisation du département de production. Cette réorganisation fournit alors les conditions qu'il fallait afin que les opérateurs pussent continuer de se conduire en système autorégulateur après avoir fini de se réentraîner. En même temps il y eut une amélioration bien marquée dans le rendement.

In der Industrie ist es nicht ungewöhnlich, dass die Leistungen eines Angelernten fallen, wenn er in die Produktion eingereiht wird. Während des Anlernens wird der Lernende—unter Gesichtspunkten der Regel-Technik—als ein selbst-regulierendes System behandelt. In der normalen Produktion dagegen findet der Arbeiter seine Aufgabe darauf beschränkt, Leistungen zu vollbringen, deren Kontrolle hauptsächlich in den Händen der Inspektion liegt. In dem hier beschriebenen Experiment wurde zugleich mit der Einrichtung einer Anlern-Abteilung die Produktion re-organisiert. Diese Re-Organisation sorgte für Bedingungen, unter denen die Arbeiter, nach Wiederanlernung, fortfahren konnten, als selbst-regulierendes System zu wirken. Das führte zu einer wesentlichen Verbesserung der Leistungen.

References

Argyris, C., 1957, *Personality and Organisation* (New York: Harper & Brothers).

Belbin, E., Hill, F., and Belbin, R. M., 1957, The results of three different methods of operator training. *Ergonomics*, **1**, 39–50.

Crossman, E. R. F. W., 1959, A theory of the acquisition of speed-skill. *Ergonomics*, **2**, 153–166.

Kay, H., 1957, Information theory in the understanding of skills. *Occup. Psychol.*, **31**, 218–224.

King, P. H. M., 1948, Task Perception and interpersonal relations in industrial training, Part II *Human Relations*, **1**, 373–413.

Rice, A. K., 1958, *Productivity and Social Organisation* (London: Tavistock Publications Ltd.).

Seymour, W. D., 1954, *Industrial Training for Manual Operations* (London: Pitman).

Singleton, W. T., 1958, Production problems in the shoe industry. *Ergonomics*, **1**, 307–313.

Trist, E. L., and Bamforth, K. W., 1951, Some social and psychological consequences of the long-wall method of coal-getting. *Human Relations*, **IV**, 3–38.

NOTE ON CURRENT TRENDS IN LITERATURE ON TRAINING

By Ezra V. Saul

Institute for Applied Experimental Psychology, Tufts University, Medford, Massachusetts

This note outlines the experience of the Human Engineering Information and Analysis Service project at Tufts University. Sources of training research, some of the topics receiving emphasis and possible reasons for the dearth of published research on training in industry are discussed. A fuller article on the project will be published in a subsequent number of this Journal.

We have recently estimated the annual output of published material pertinent to training to be about 500 journal articles and books a year. This estimate explicitly excludes a large part of the literature on human learning and also on education. Pertinent training literature derives from over 50 different journals and periodicals and is considerably supplemented by reports of governmental origin. The majority of these publications appear in the English language. Our experience indicates that government and government-sponsored agencies are the most productive of systematic research and application in this area: in the U.S. especial mention may be made of the U.S.A.F. Personnel and Training Research Center, Lackland Air Force Base, Texas; the Human Resources Research Office, Washington University, D.C., the U.S.N. Office of Naval Research, Washington, D.C., and the U.S. Naval Training Devices Center, Port Washington, Long Island.

Training topics receiving emphasis in recent published literature, have notably included training aids and devices, supervisory and human relations training, and training in trouble-shooting and maintenance of complex equipment. Publications on training aids and devices reveal a renewed interest in the use of graphs, pictures, motion-picture films, etc. as training aids. In addition, there is a considerable concern with television and complex simulators as training devices. The U.S. Naval Training Devices Center has recently published several reports reviewing much of this research (Greenhill 1953, Hoban and Van Ormer 1950, Human Engineering Department, U.S. Naval Training Device Center 1956, Saul *et al.* 1954, Special Devices Center 1953).

A useful bridge between the recent work on training devices and research on determinants of effective training for the use and maintenance of complex equipment is a series of very provocative reports by Miller (1953 a, b, c, d, 1954). In these articles he sets forth general principles and procedures for establishing training requirements for existent as well as projected, but as yet non-existent, equipments. He also outlines methods for setting up specific training programmes, and methods of instruction and training devices which would meet the determined training requirements. Though these reports were generated in a military context, their applicability to industry is obvious and merits consideration by industrial training personnel.

Unfortunately, the literature on training in trouble-shooting, maintenance, supervision and human relations is not as succinctly summarized as the work

on training aids and devices and on analytic procedures. However, examination of the *Title Abstract Bulletin* of the U.S. Armed Services Technical Information Agency reveals many technical reports being published under military aegis on training in trouble-shooting and maintenance of complex equipments such as aircraft and electronic equipment. Though much of this material is specific to particular equipment, some reports such as those emanating from the Education Research Corporation, Cambridge, Mass., tend to highlight general principles and procedures applicable to a variety of trouble-shooting activities and equipment encountered in industry.

In similar fashion the literature pertinent to supervisory and human relations training is readily available upon search of the *Industrial Arts Index* and *Psychological Abstracts*. This literature is characterized by many specific applications of such training in varied industrial settings, with a limited number of studies reporting the measured effectiveness of such training programmes and the requisite conditions for their effective implementation.

The impression one gets from reviewing the training literature is that relatively little research on industrial training and application is published and what little does appear is frequently unsystematic, superficial, and sketchy. This lack of published industrial information is extremely unfortunate because in many instances, we know that data exist as a result of industrial research or application, but have not been communicated by way of journal publication.

Though several factors may cause this failure to communicate, we perceive two as being of major significance. The first is the lack of motivation, effort, and skill of training personnel to undertake the task of submitting such information for publication in journals. The second, and probably the more important, is the policy in some industrial establishments of treating such information as ' Company Restricted ' with a view to enhancing the particular company's competitive position. It is obvious that both these factors operate, in the long run, to decrease the effectiveness of industrial training personnel with resultant losses in the efficiency of industrial workers. Some of our recent experience suggests that industrial concerns might be less reluctant to release ' Company Restricted ' human factors information to an ' ethical documentation centre ' than to open journal publication. Suffice it to say that serious efforts are required to make available more of the information on human factors originating in industrial settings.

The preparation of this note was supported in part by Contract Nonr 494(13) between the U.S. Office of Naval Research and Tufts University. The opinions of the author do not necessarily reflect those of the U.S. Office of Naval Research.

Ce note décrit de façon brève l'expérience du projet de l'information au sujet de la Mécanique Humaine et le Service d'analyse à l'université de Tufts. On entrevoit les sources de recherches sur l'entraînement, quelques sujets dont on s'occupe le plus, et on discute des raisons possibles pour le manque de recherches publiées sur l'entraînement industriel. Un article plus ample sur le projet sera publié dans une édition suivante de ce journal.

Notiz über die herrschenden Richtungen in der Literatur über Ausbildung. Diese Notiz gibt die Erfahrungen von Tufts University wieder, die mit dem Human Engineering Informations und Auswertungsdienst gemacht wurden. Die Quellen der Ausbildungsforschung, einige Themen, die vorgezogen werden und die möglichen Gründe für den Mangel an Veröffentlichungen über Forschungen in der Industrie werden diskutiert. Ein ausführlicherer Artikel über dieses Project wird in einer der folgenden Nummern dieser Zeitschrift veröffentlicht werden.

References

Greenhill, L. P. (Coordinator), 1953, A bibliography of production, utilization and research on instructional films. Contract N6onr–269, Proj. 20E–4, TR SPECDEVCEN 269–7–40, 145 pp. ADC, Pennsylvania State University, Instructional Film Research Program.

Hoban, C. F., Jr., and Van Ormer, E. B., 1950, Instructional film research 1918–1950. Rapid mass learning. Contract N6onr–269, Proj. NR 781–005, HE Proj. 20–E–4, Tech. Rep. 269–7–19, 179 pp. Special Devices Center, Port Washington, L.I., N.Y. (Instructional Film Research Program, Pennsylvania State University.)

Human Engineering Department, U.S. Naval Training Device Center, 1955, Instructional television research reports. Tech. Rep. NavTraDevCen 20–TV–4, Navexos P–1544, 372 pp. U.S. Naval Training Device Center, Port Washington, L.I., N.Y.

Miller, R. B., 1953, A method for determining human engineering design requirements for training equipment. Contract AF33 (038)–22638, RDO No. 694–44, WADC Tech. Rep, 53–135, 17 pp. Aero Medical Lab., WADC, ARDC, Wright-Patterson AFB, Dayton, Ohio. (American Institute for Research); 1953 b, A method for man–machine task analysis. Contract AF 33(038)–22638, RDO No. 694–44, Tech. Rep. 53–137, Aero Medical Lab., WADC, ARDC, Wright-Patterson AFB, Dayton, Ohio; 1953 c, Handbook on training and training equipment design. Contract AF 33(038)–22638, RDO No. 694–44, Tech. Rep. 53–136, 339 pp. Aero Medical Lab., WADC, ARDC, Wright-Patterson AFB Dayton, Ohio. (American Institute for Research); 1953 d, Human engineering design Schedule for training equipment. Contract AF 33(038)–22638, Tech. Rep. 53–138, 34 pp. Aero Medical Lab., WADC, ARDC, Wright-Patterson AFB, Dayton, Ohio. (American Institute for Research); 1954, Psychological considerations in the design of training equipment. Contract AF 33(616)–2080, Proj. 7197, Tech. Rep. 54–563, 138 pp. Aero Medical Lab., WADC, ARDC, Wright-Patterson AFB, Dayton, Ohio.

Saul, E. V., Cornehlsen, J. H., Devoe, D. B., Niccoll-Ehmer, Marjy, Hansen, C. J., Jaffe, J., Raben, Margaret W., and Zurier, Janet, 1954, A review of the literature pertinent to the design and use of effective graphic training aids. Contract Nonr 494(08), Human Engng, Rep. SDC 494–08–1, Prelim. Draft, 192 pp. Special Devices Center, Port Washington, L.I., N.Y. (Tufts College.)

Special Devices Center, 1953, Instructional film research reports. Navexos P–1220, Tech. Rep. SDC 269–7–36, 600 pp. Special Devices Center, Port Washington L.I., N.Y. (Pennsylvania State University).

CIRCUIT TRAINING

By G. T. Adamson

Department of Physical Education, The University, Leeds

The paper describes a form of training in which there is progressive loading of the individual. The ' circuit ' includes a number of exercises, usually nine to twelve, selected so as to improve general muscular condition, and circulatory and respiratory responses. The main assumption underlying this approach is that general fitness is determined by : *muscular strength*, the capacity to exert force against *resistance* ; *muscular endurance*, the capacity for continuous performance of heavy activity making small demand on circulatory and respiratory functions ; *general endurance*, the capacity to continue sub-maximal contractions of sufficient intensity to make demands on circulatory and respiratory functions ; *muscular power*, the capacity to develop horsepower. Circuit training consists of the following phases : teaching, testing, timing, training and retesting in accordance with a target time. Some figures are given showing improvements in performances attained by a group of 20 university students attending training for eight weeks on a circuit consisting of twelve exercises.

§ 1. Introduction

Circuit training is a form of progressive resistance loading and is designed to improve general muscular and circulo-respiratory conditions. General fitness (if it exists) is to be considered as composed primarily of the four qualities : muscular strength, muscular endurance, general endurance and muscular power. Since current terminology in this field is neither consistent nor precise it is necessary to define briefly the above qualities and to indicate the method of their measurement.

Muscular strength: the capacity of an individual to exert muscular force against a resistance, maximum muscle strength being measured by use of near-immovable resistance under isometric conditions. From the various kinds of strength measuring instruments available, the spring steel elliptical dynamometer for strength of grip, and the hydraulic dynamometer for strength of back were selected.

Muscular endurance: the capacity of an individual for continuous performance of relatively heavy localized activities which make only small demands on the functions of circulation and respiration before local fatigue terminates performance.

It is usually measured in terms of repetitions of such standardized low-repetition localized exercises as ' chinning the beam ' or ' dipping ' between parallel bars. In each case the performer has to cope with total body weight by means of relatively small muscle groups.

General endurance: represents the individual capacity to continue sub-maximal contractions of a number of muscle groups with sufficient intensity to make demands on the functions of respiration and circulation before general fatigue terminates performance. It depends more on the athletic condition of the heart than on skeletal muscular strength. For administrative reasons, in spite of its obvious weaknesses, the Harvard Step Test on a 17 inch step was used in preference to the all-out treadmill run in order to check individual improvement in this quality.

Muscular power: represents the individual capacity to develop horse-power from the daily fractional horse-power of the office clerk to the 14 h.p. of the world record 100 yard sprinter.

One test of the ability to develop power relative to the body weight is the vertical jump, which measures the vertical height through which a performer can project his centre of gravity in a simple upward jump off both feet.

§ 2. Methods of Training

Tests carried out on large numbers of athletes of all kinds have shown that they usually possess high levels in the above qualities when compared with the average 19-year-old university student. Circuit training evolved out of an attempt to find a method of training which would enable the average student to acquire some of the high level stamina of say the distance runner, together with some of the strength of the weight lifter and the speed of the sprinter.

The amount of work done per second seems to be the critical variable on which extension of limits of performance depends, and the principle of progressive loading appears to supply the answer to the problem of control of fitness qualities by work rate. Progressive resistance for strength and power, either by imposition of progressively greater loads or higher work rate, produces increase in muscle strength by fibre hypertrophy. As a result of this increase in strength fewer motor units of the muscle are required for a given load and these may be alternated over a longer time thus increasing muscular endurance. Specific progressive resistance for muscular endurance is effective through perfection of movement and improved blood supply to the muscle. Progressive loading of activities such as exercises involving severe leg work, in addition to increasing the strength and muscular endurance of the muscles concerned, induces hypertrophy and increased capillarization of cardiac and peripheral muscle, thereby increasing circulo-respiratory endurance.

The use of weight training for strength promotion has now become an established and approved practice, and it is assumed here that it offers the best medium for the most rapid and enduring acquisition of strength, at least until the recent studies of Müller (1959) have been thoroughly substantiated.

There seems to be an optimum work rate and duration for the most rapid increase in strength. Through trial and error the weight lifter has discovered that it is best achieved by using sets of exercises of low repetition and ‘ near maximal resistance ’. This high work rate, however, can only be maintained for short periods and therefore has little or no cardiovascular training effect.

Current research on endurance training suggests that it must involve a progressive resistance loading of the circulatory and respiratory systems over long periods, examples being Fartlek training, Interval running and Repetition running. No single type of exercise seems capable of developing both strength and endurance. Weight training seems to have little or no effect on circulo-respiratory condition.

Circuit training, which is really interval exercising, endeavours to obtain both strength and endurance effects by timed control of sub-maximal training.

The individual aims to do more work in a fixed time or the same work in less time.

§ 3. Stages of Training

Exercises, usually about 9–12 in number, are selected and arranged in the form of a circuit round the gymnasium and numbered consecutively. The selection and arrangement of these exercises is such that the period of training (usually less than half an hour) will have a simultaneous and positive effect on all four qualities. Their arrangement allows the individual to progress steadily round the circuit without undue local fatigue, and in addition provides information on the total work done. The exercises include the use of weights (including handling of total body weight) as well as general endurance exercises such as squat thrusts. The administration of this training to an individual is best achieved in three stages.

Teaching: at his first attendance the performer practises the exercises until he achieves the standardized performance. He then performs three laps of the circuit doing an elementary ‘ dose ’ well within his capacity at each exercise. On the next two attendances he repeats his three laps, thereby becoming more and more efficient at the exercises. On his fourth attendance his improvement due to motor learning is assumed to have been generally achieved and he is ready for his maximal tests.

Testing: the maximal tests at each exercise are performed in circuit order so that the cumulative fatigue effect is the same in testing as in the subsequent training. Maximum figures are recorded on his score card, and a training rate is now fixed. The most suitable dose has been found to be $\frac{1}{2}$ maximum at each exercise for a circuit of three laps.

Timing: at his next attendance he is ready for his time trial. This is the time taken to complete three laps of the circuit at the prescribed work rate, without rest between activities. He is now allocated a ‘ target ’ time usually $\frac{1}{3}$ less than his recorded time. This target time he must attain before he is ready for re-testing.

§ 4. Some Experimental Findings

A random selection was made of 20 university students attending the gymnasium for circuit training once per week for 8 weeks. In each session they performed a triple dose at half maximum effort on a circuit consisting of the following 12 exercises.

1. Stepping on a 17 in. bench	$\frac{1}{2}$ max/min
2. Squat Thrusts	,, ,, ,,
3. Heave to beam (‘ Chins ’)	$\frac{1}{2}$ maximum
4. Trunk ‘ curls ’ from lying on back	$\frac{1}{2}$ max/min
5. Rope heave swing to touch high beam with feet	$\frac{1}{2}$ maximum
6. Climb up one 15 ft wall ladder and down next	$\frac{1}{2}$ max/min
7. Jump on and off 12 in. bench holding pair of 16 lb dumb bells	$\frac{1}{2}$ max/$\frac{1}{2}$ min
8. ‘ Press-ups ’ from floor	$\frac{1}{2}$ max

9. Climb up 15 ft rope ladder and down next — ½ max/min
10. Walk on hands on parallel bars 12 steps forward and and backwards — ½ max/min
11. Bend forward to 45° with bar bell weighing ⅓ body weight across shoulders — ½ max/½ min
12. Squat jumps — ½ max/min

Increase of Mean Performance Readings due to 8 weeks' Training

Quality	Test	Before training	After training
Muscular strength	Sum of grip strengths	183·8 lb	198·7 lb
	Lumbar pull	292·1 lb	318·5 lb
Muscular endurance	'Chins'	4·6	6·6
	'Dips'	6·5	11·5
General endurance	Harvard step test	81·4	87·0
Muscular power	Vertical jump	19·4 in.	21·8 in.

Il s'agit d'un système d'entraînement avec chargement progressive de l'individu. Le 'circuit' embrasse plusieurs exercices, le plus souvent neuf à douze, choisies avec le but d'améliorer la condition musculaire générale, et les réponses circulatoires et respiratoires. L'hypothèse principal sur lequel on a fondé ce système est que le bien-être général est determiné par: la force musculaire, la capacité d'exercer de la force contre de la résistance:

L'endurance musculaire, la capacité d'exécuter de façon continue une activité exigeanté mais qui n'exige pas beaucoup des fonctions circulatoires et respiratoires; l'endurance général, la capacité de continuer des contractions moins que maximum d'une intensité telle qu'elle soit exigeante pour les fonctions circulatoires et respiratoires; la puissance musculaire, la capacité de développer de la puissance en chevaux.

L'entraînement à circuit consiste en les phases suivantes; l'enseignement, les épreuves, le pointage, l'entraînement et de nouvelles épreuves rapportées à un temps qu'on souhaite d'atteindre. Des chiffres sont donnés qui montrent les améliorations de rendement atteintes par un groupe de 20 étudiants qui ont entraîné pendant huit semaines sur un circuit qui comprenait 12 exercices.

Die Arbeit beschreibt eine Trainings-form, bei der dem Individuum eine progressive Belastung auferlegt wird. Das Allgemeintraining umfasst eine Anzahl von Uebungen, gewöhnlich 9–12, die so ausgewählt sind, dass der Allgemeinzustand der Muskulatur und der Kreislauf und Atem-Funktionen verbessert wird. Dieses Vorgehen beruht auf der Grundannahme, dass der Allgemeinzustand durch folgende Grössen bestimmt wird:

Muskelkraft; die Fähigkeit, gegen einen Widerstand Kraft auszuüben; Muskelausdauer, die Fähigkeit, zu fortgesetzter Ausführung schwerer Arbeit bei geringen Anforderungen an Kreislauf- und Atem-Funktionen; Allgemeine Ausdauer, die Fähigkeit, zu fortgesetzten sub-maximalen Kontraktionen genügender Intensität, um die Kreislauf- und Atem-Funktionen zu belasten; Muskelleistungsfähigkeit, dh. die Fähigkeit, Pferdekräfte zu entwickeln.

Das Allgemeintraining besteht aus folgenden Phasen: Einüben, Testen, Zeit nehmen, Trainieren und Wieder-Testen.

Einige Zahlen werden wiedergegeben, die Verbesserungen der Leistung einer Gruppe von 20 Universitäts-Studenten zeigen, die 8 Wochen an einem Allgemeintraining mit 12 Uebungen teilgenommen haben.

Reference

Müller, E. A., 1959, Training muscle strength. *Ergonomics*, 2, 216–222.

THE LIMITATIONS OF A 'PROCRUSTEAN' APPROACH TO THE OPTIMIZATION OF MAN–MACHINE SYSTEMS

By F. V. Taylor and W. D. Garvey
U.S. Naval Research Laboratory, Washington, D.C.

Two rather different human factor approaches may be distinguished in efforts to optimize the performance of man–machine systems. One seeks, through the training of the operator, to adjust the human component to the requirements of the system. The other attempts to enhance system performance by adjusting the mechanical elements to fit the man.

Although much has been accomplished through training programmes, this approach is limited. In the first place, no amount of effort devoted to training operators can make the performance of some man–machine systems adequate to their tasks. A second limitation of the training approach is just beginning to be appreciated. In many instances it is possible, through operator training, to eliminate performance differences among man–machine systems of different intrinsic merit. This might lead one to choose an inferior design in the place of a better one since, under normal operation, they would all appear to be equivalent. However, if the operators were stressed, the fundamental inferiority of the chosen system might reassert itself. The study reported here has, in fact, shown that two different tracking systems, made equivalent through training, revert to their original order of merit when the operators are subjected to any one of a wide variety of 'task-induced' stress situations.

§ 1. Introduction

It is now common to regard the human operator of a machine and the machine itself as two elements in one overall man–machine system. The pilot and his plane, the helmsman and his craft, and the lathe operator with his lathe are examples of such system. To improve the performance characteristics of these man–machine combinations, one has the choice of either trying to alter the man so that he fits the machine better, or modifying the mechanisms to fit the man. The latter approach is that of the engineer and the new specialist called the human engineer, while efforts to adapt the man to the machine characterize the work of the training expert.

It is our purpose to take a critical look at the training approach, called here 'Procrustean' after the legendary highwayman who 'adapted' his victims to an iron bed by either stretching or cutting off their legs. In particular, three limitations will be considered.

§ 2. Cost

The high cost of training in terms of both money and time is one of its most obvious and serious limitations. It is estimated that in World War II it cost \$50 000 to train a single American fighter pilot, and that one-fourth of his entire service life was spent in learning his job. In industry, the cost of training relative to the productive life of the operator is certainly less than in the military but, absolutely, it is a matter of millions of dollars and thousands of man-years. Training is, indeed, a costly affair. It would certainly be better if one could entirely dispense with it.

Of course, this is not possible in the majority of work situations, but in certain man–machine systems, adequate engineering of the machine reduces

training requirements enormously. In one study (Taylor 1957) for example, the majority of subjects, using two joysticks and two X–Y displays, could control simultaneously in *four coordinates* with absolutely no practice when the control system was properly ' human-engineered '. In contast, without the human-engineering features, the task was so difficult that to control in even *one* coordinate required considerable training. Clearly, in some instances, adapting the machine to the man has a great advantage over efforts to adapt the man to the machine.

§ 3. Effectiveness

A second limitation of training in the systems context is that it sometimes fails to work. No amount of training will ever make some man–machine systems function successfully. For example, no pilot, regardless of how highly practised and skilled he may be, can, without devices to aid stabilization, position an aeroplane with sufficient accuracy for missile firing. Likewise, with conventional displays, it is impossible for the human controller to hold a helicopter in a stationary hover in blind flying conditions. Training is not the answer here.

In order to bring such systems up to a tolerable level of performance, it is necessary to shift some of the burden of controlling from the man to the machine. One way of doing this is to build into the aircraft data processing networks which compute control information before it is displayed to the pilot. In the case of the helicopter, such a human engineering solution has been shown to improve hovering performance by 500 per cent over and above all that had been achieved through training (Sweeney *et al.* 1957).

A clear example of the relative ineffectiveness of training, as contrasted with human engineering, is provided by a study performed by Rund *et al.* (1957). They compared the change in performance which resulted from 10 days of practice with that which was achieved by modifying the electronic system components to accord better with the characteristics of the human operator. Employing a binary display which indicated direction but not extent, the subjects tracked through a control system which had the dynamics of an aeroplane responding in heading. The human engineering variable was the degree to which the control system was ' quickened '.

What this term means may best be understood by considering an example. Without quickening, lags occur in the response of an aeroplane (and in the majority of other control systems) to the guidance signals inserted by the pilot. These arise from the physical properties of the aircraft and the aerodynamics involved in its motion. To fly an unquickened aeroplane without oscillating or ' over-controlling ', the pilot has to take these lags into account and to anticipate and compensate for their effects. Quickening is a process for making this anticipation unnecessary by displaying to the pilot an indication which contains not only the aircraft heading but the derivatives of heading as well, so that his responses can bear a direct and simple relationship to what he sees (Birmingham and Taylor 1954). With full quickening, the pilot only has to insert a signal which is proportionately related to the display indication; with partial quickening some slight anticipation is necessary, but less than with no quickening. ' Super-quickening ' is achieved by electronically differentiating the fully quickened

signal and combining this derivative term with the quickened indication (Rund *et al.* 1957). This has the effect of ' speeding-up ' the display so that in responding the pilot is less under the pressure of time.

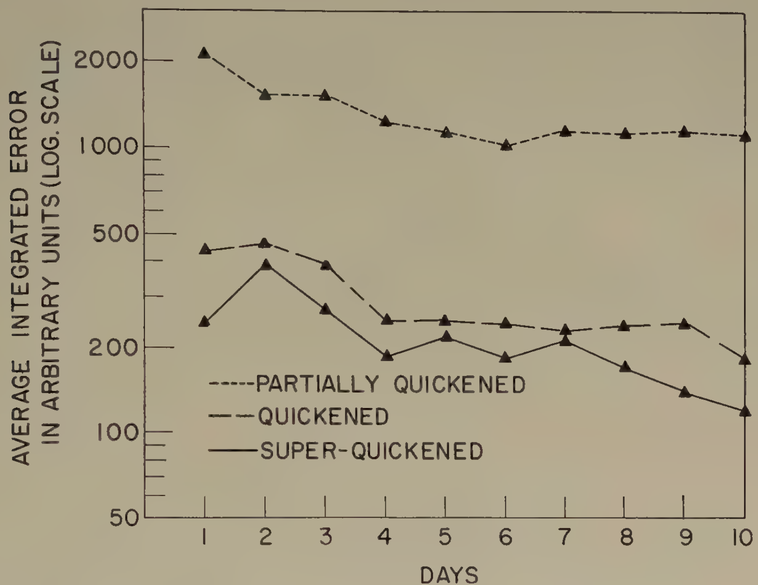


Figure 1. Performance plots of three man–machine systems. Each point is based upon results with six subjects.

The performance data are shown on a semi-log plot in Fig. 1. The 10 days of practice produced about a two-to-one improvement in performance for all degrees of quickening. However, the average difference between the least and the most adequately quickened systems is nearer ten to one. Although it would be foolish to generalize the precise values obtained in this particular experiment, the five-to-one difference favouring the effectiveness of the machine design approach certainly indicates that, in some circumstances, training is by no means the best technique for optimizing the performance of man–machine systems.

§ 4. Disruption of Performance under Stress

Although the high cost and limited effectiveness of training are disadvantages, they do not constitute positive dangers. Yet, evidence is beginning to accumulate from a series of ' task-induced ' stress studies (Garvey 1957) that an unenlightened use of training may actually constitute an operational hazard. To date, the studies suggest that stress disrupts most the performance of those man–machine systems which place the heaviest demands upon the operator. In one of the experiments, the stress effects were measured for two systems of different human engineering merit, but which had been equated in performance, before stress, by operator training.

The two systems which were compared are shown in block diagram in Fig. 2. These are tracking systems in which the operator manipulates a spring-restrained joystick to control a target on a compensatory display.

In the position-control device, the output of the subject appears directly on his display without transformation. In the acceleration-control system, the tracker's output is transformed by two integrators so that the subject controls the acceleration of the target dot, rather than its position.

Two matched groups of subjects were practised for 23 sessions of ten 60 sec trials. Two sessions per day were given, one in the morning and one in the afternoon. One group used the position-control device and the other the acceleration-control system.

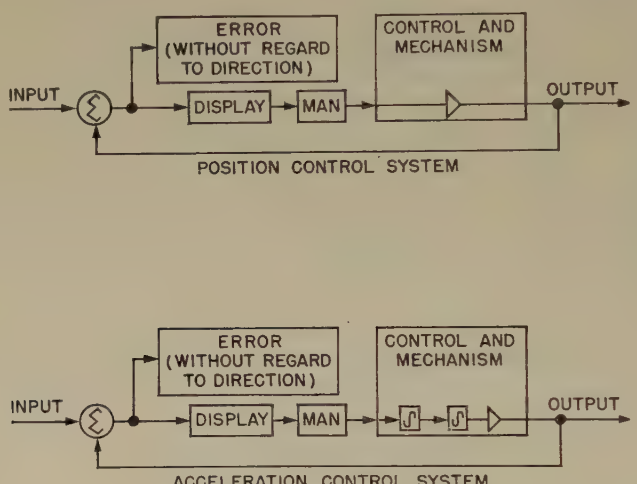


Figure 2. Block diagrams of the control systems used by Garvey (1957).

The learning curves for the two systems are shown in Fig. 3. At the outset and for the first several days of training, the position-control system was significantly superior to the acceleration-control device. As training progressed, however, the difference between the two systems lessened until it finally disappeared. From the 17th day on, the two systems were equivalent in performance. This demonstrates that, under some circumstances, training can wipe out intrinsic differences between systems. The question is, however, will the difference remain submerged under other than optimum conditions ?

At the end of training, both groups tracked for a continuous run lasting one hour and also performed while subjected to six different types of ' task-induced stress '. The stresses were produced by requiring the operators to track under the following conditions: (I) *Reversed display-control relationships.* During training, movement of the subject's control to the right caused the tracking dot to move to the right ; during ' stress ' movement of the control to the right caused the dot to move to the left. (II) *Left-hand tracking.* During pre-stress training, the subjects had tracked with the right hand : during ' stress ' they tracked with the left. (III) *Two-hand tracking.* Subjects were required to track two dots simultaneously, one with a right-hand control, the other with a left-hand control. Both dots were driven by the same course which was employed during training. Only the performance of the right-hand system was used in analysing the results. (IV) *Two-coordinate tracking.* A single target was tracked in both the horizontal and vertical coordinates with a single two-coordinate control stick

operated by the right hand. The course input to the system was that used during training, except that its path of movement was rotated 45° from the horizontal. Only the performance in the horizontal coordinate was used in the data analysis. (V) *Secondary visual task.* While performing the same tracking task as employed during training, the subjects had to detect and report the range and bearing of targets which appeared on a simulated radar scope mounted above the tracking display. The radar display was changed every 5 seconds, although targets appeared in only half of the views. (VI) *Secondary arithmetic task.* While tracking, the subjects were repeatedly required to subtract mentally a one-digit from a two-digit number and to call out the result.

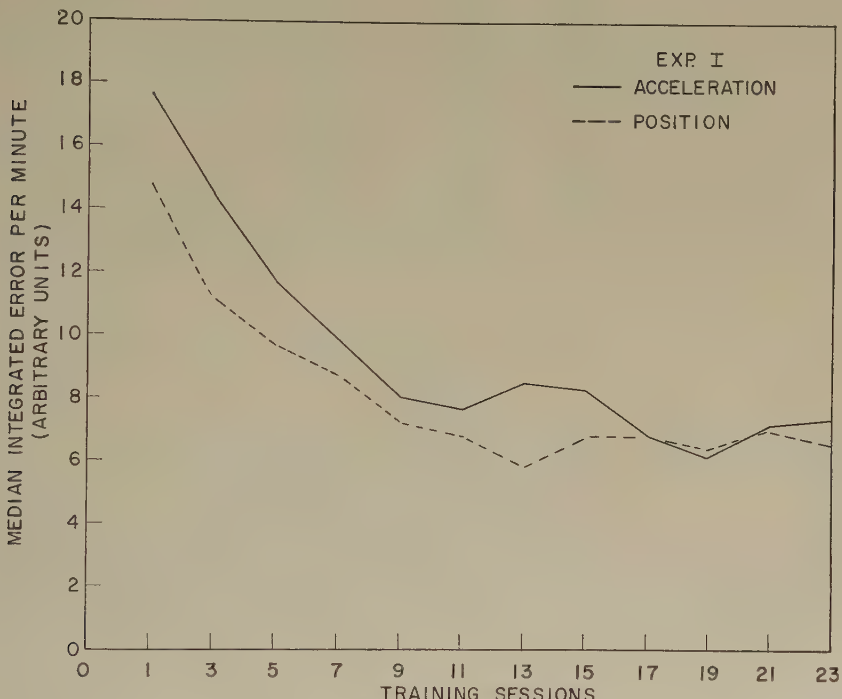


Figure 3. Change in performance with training with two different types of control-systems. Each point is based upon results with eight subjects.

Each stress condition was presented on a different day in a single block of ten trials, preceded by five practice trials and followed by ten practice trials.

Figure 4 shows performance with the two tracking systems throughout the course of the one-hour continuous run, which was made after the subjects had completed their training. It may be seen that, at the outset of the run, the two systems were equivalent but that performance with the acceleration-control deteriorated more rapidly than did that with the position-control. The final marked drop in the curves is probably due to the motivating effect on the subjects of knowing that the test would soon be over. A similar ' end spurt ' has been found in other studies of vigilance and fatigue (Deese and Ormond 1953, Garvey *et al.* 1958, Jackson 1956).

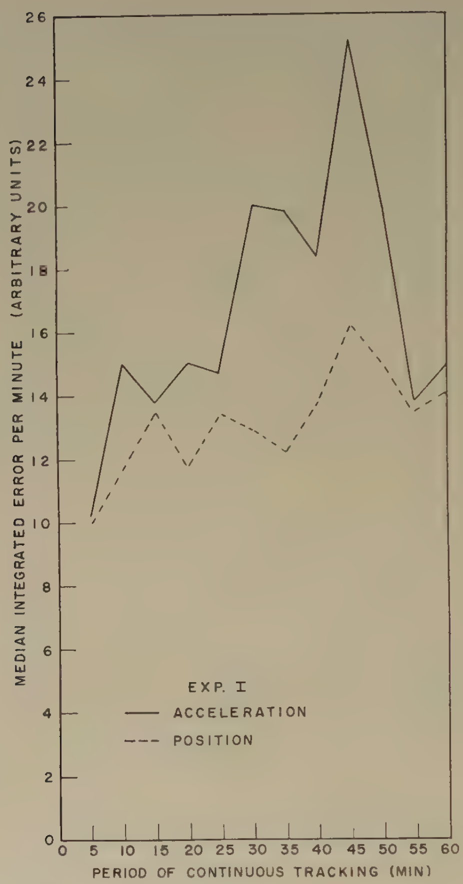


Figure 4. Change in performance with continuous tracking. Each point is based upon results with eight subjects and represents error per minute recorded for successive five-minute intervals.

The effects of the six different stress conditions are summarized in the bar graph shown in Fig. 5. On the left, is shown the performance of the two systems after training, and without stress. There is no significant difference between them in this case. However, with every form of stress, except that induced by requiring that the tracking be done with the untrained hand (Stress condition II), performance with the acceleration-control is disrupted significantly more than that with the position-control.

It is thus clear that although differences between different systems in human-engineering terms may be masked by training, the superiority of one system as compared with another may reassert itself when the operator is called upon to work under stressful conditions. This means that, in some cases, the use of training to optimize the performance of a man–machine system may, like papering over the cracks in a wall, have serious and undesirable consequences. Certainly, if systems must perform well under combat or in any other-than-optimum situations, training in the absence of stress should not be used as a substitute for adequate equipment design.

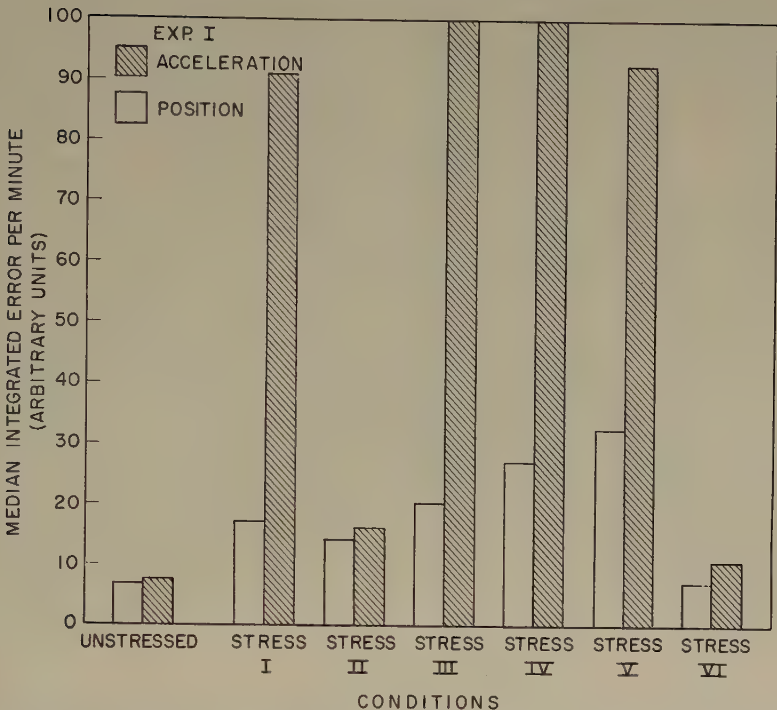


Figure 5. Effects of task-induced stress on system performance. Each bar is based upon results with eight subjects.

On peut distinguer deux méthodes différentes de s'attaquer à l'élément humain dans les tentatives de porter à l'optimum le rendement des systèmes ' homme-machine '. L'une essaie, par moyen de L'entraînement de l'opérateur, d'ajuster l'élément humain aux besoins du système. L'autre aborde le problème de réhausser le rendement du système en réglant les éléments mécaniques selon l'homme.

Bien qu'on eût accompli beaucoup par les programmes d'entraînement, il y a un limite à ce qu'on peut faire par cette voie. Premièrement, quelque effort qu'on fasse pour entraîner des opérateurs ne saurait réhausser le rendement de certains systèmes ' homme-machine ' au point de suffire à leur tâche. Une seconde limitation à la méthode d'éntraînement commence seulement à être comprise. Dans beaucoup de cas il est possible, par moyen de l'entraînement de l'opérateur, d'éliminer les différences de rendement parmi les systèmes ' homme-machine ' dont les mérites intrinsèques sont différents. Cela pourrait amener a préférer une machine inférieure à une autre qui serait mieux dessinée puisque, dans les conditions normales, elles paraîtraient toutes équivalentes. Néanmoins, si les opérateurs sont surmenés, l'infériorité foncière du système choisi pourrait se révéler. L'étude ici rapportée a démontré, en effet, que deux systèmes différents à tracer, qui s'équivalaient à la suite de l'entraînement, reviennent à leurs mérites relatifs primaires quand on fait subir, aux opérateurs n'importe lequel d'un grand nombre d'états de surmenage provoqués par leur tâche.

Auf 2 verschiedenen Wegen kann versucht werden, die Funktion von Mensch-Maschine-Systemen zu verbessern. Der eine sucht durch Training des Arbeiters die menschlichen Faktoren den Anforderungen der Maschine anzupassen, der andere die Elemente der Maschine auf den Menschen auszurichten.

Wenn auch viel durch Trainings-Programme erreicht wurde, ist dieser Weg doch begrenzt, weil einige Mensch-Maschine-Systeme sich auch durch einen sehr grossen Aufwand fär das Training des Arbeiters nicht zu einer ihrer Aufgabe entsprechenden Funktion bringen lassen. Eine andere Begrenzung wurde neuerdings erkannt. In vielen Fällen ist es möglich, durch Training des Arbeiters Leistungsunterschiede zwischen Mensch-Maschine-Systemen verschiedener Güte zu beseitigen. Das könnte zur Wahl eines weniger guten statt eines besseren Systems führen, da beide unter normalen Bedingungen gleichwertig erschienen. Würde der Arbeiter dagegen stärker belastet, so könnte die grundsätzliche Minderwertigkeit des gewählten Systems sich wieder bemerkbar machen. Die hier vorgebrachte Untersuchung hat tatsächlich gezeigt,

dass 2 verschiedene Systeme von Folgebewegungen, die durch Training leistungs-gleich gemacht wurden, in ihre ursprüngliche Ordnung der Leistungsgüte zurückfielen, wenn die Aufgaben erschwert wurden.

References

Birmingham, H. P., and Taylor, F. V., 1954, A Design Philosophy for Man–Machine Control Systems. *Proc. Inst. Radio Engrs, N.Y.*, **42**, 1748–1758.

Deese, J., and Ormond, E., 1953, Studies of Detectability During Continuous Visual Search. *Wright Air Development Center Report* **53–8.**

Garvey, W. D., 1957, The Effect of ' Task Induced Stress ' On Man–Machine System Performance. *U.S. Naval Research Laboratory Report* 5015.

Garvey, W. D., Henson, J. B., and Gulledge, I. S., 1958, Effect of Length of Observing Time on Earth Satellite Visibility. *U.S. Naval Research Laboratory Report* 5094.

Jackson, K. F., 1956, Aircrew Fatigue in Long Range Maritime Reconnaissance—Pilot Performance. *Flying Personnel Research Committee* Report No. **907.2.**

Rund, P. A., Birmingham, H. P., Tipton, C. L., and Garvey, W. D., 1957, The Utility of Quickening Techniques in Improving Tracking Performance with a Binary Display. *U.S. Naval Research Laboratory Report* **5013.**

Sweeney, J. S., Bailey, A. W., and Dowd, J. F., 1957, Comparative Evaluation of Three Approaches to Helicopter Instrumentation for Hovering Flight. *U.S. Naval Research Laboratory Report* **4954.**

Taylor, F. V., 1957, Simplifying the Controller's Task Through Display Quickening. *Occ. Psychol.*, **31**, 120–125.

PHYSICAL TRAINING IN RELATION TO THE ENERGY EXPENDITURE OF WALKING AND TO FACTORS CONTROLLING RESPIRATION DURING EXERCISE

By J. E. Cotes and F. Meade

Medical Research Council, Pneumoconiosis Research Unit,
Llandough Hospital, Penarth, Glamorgan, Wales

In eleven National Service men during their preliminary training course there was a decrease in energy expenditure and 'vertical work' done in walking at $3\frac{1}{2}$ m.p.h. This is attributed to increased economy of movement since the ratio of energy expended to 'work' done remained constant. The reduction in exercise ventilation on switching the inspired gas from air to oxygen also decreased over the training period, suggesting improved oxygenation of the blood in the lungs. There was no concurrent change in pulmonary diffusing capacity or ventilation equivalent. No experimental evidence was obtained to support the hypothesis that as a result of this training the body temperature rises less on exercise and that this contributes to the changes in exercise ventilation.

§ 1. Introduction

The amount of air a subject breathes per minute in performing a given task decreases with practice or training. For this there are two main reasons: first, less energy is expended; secondly, the ventilation per unit of energy expenditure (which is effectively the ventilation equivalent) may diminish as a result of changes in the factors which control respiration. These factors include: changes in the oxygen tension of arterial blood and in the carbon dioxide tension of the tissues of the respiratory centres in the brain; changes in body temperature; and changes in factors either directly or indirectly related to the muscular contractions and bodily movements which occur (see Comroe 1944, Gray 1950).

In the present investigation the effects of training on the respiration of subjects walking at $3\frac{1}{2}$ m.p.h. is considered in relation to the work done, to the effect of breathing oxygen and to other factors, including body temperature, which contribute to the control of respiration.

§ 2. Method

2.1. *The Design of the Experiment*

Eleven National Service men volunteers were studied at rest and after practice, whilst walking at $3\frac{1}{2}$ m.p.h. on a horizontal motor-driven treadmill. Measurements were made of (i) body temperature, (ii) energy expenditure and (iii) ventilation under the following three conditions: whilst breathing (*a*) air, (*b*) oxygen and (*c*) carbon dioxide in oxygen. The pulmonary diffusing capacity was determined on exercise. The amplitude of the vertical oscillation of the body was measured in order to obtain the work of lifting the body in the vertical plane.

Measurements were made on four days, once before, twice during and again at the end of the standard ten-week period of training. However, not all measurements were made on all occasions. The response to breathing pure oxygen and the pulmonary diffusing capacity were measured on days 1 and 2. The responses to carbon dioxide and to body temperature were measured on days 1, 2 and 3. Only the energy expenditure and the vertical oscillation of the body during walking were measured on all four occasions. Some of the latter measurements form the basis of an analysis of the relationship between body size and the energy expenditure of walking (Cotes and Meade 1959).

2.2. *Experimental Procedure*

The subjects, whose physical characteristics are given in Table 1 and body weights in Table 2, were brought by car from the depot to the laboratory one hour after a normal breakfast or lunch. The resting studies were then carried out with the subjects wearing service dress; they changed into shorts and a vest for the exercise which followed. A mouth-piece was used in all experiments and humidified gas mixtures were delivered to it on demand from a system operated at low suction. Ventilation and energy expenditure were obtained from the analysis of expired gas by the use of a low resistance 200 cu. ft dry gas meter, Huntley gas sampling jars and a micro Scholander gas analyser (Scholander 1947): duplicate analyses were required not to differ by more than 0·03 per cent. The increase in ventilation per unit increase in alveolar pCO_2 was calculated from measurements of ventilation and of end tidal pCO_2, by use of the gas meter, a Rahn–Otis end tidal air sampler and an infra-red gas analyser (Rahn and Otis 1949). These measurements were made over 10–20 min after the start of breathing the appropriate gas mixtures which were: at rest, $2\frac{1}{2}$ per cent and 5 per cent CO_2 in O_2; on exercise, O_2 and $2\frac{1}{2}$ per cent CO_2 in O_2. The measurements on exercise were made after at least 40 min at a time when the rectal temperature was constant, as determined from continuous measurement by a copper constantin thermocouple of the type described by Meade and Bonmarito (1949). The galvanometer could be read to 0·02°c.

Table 1. Age and anthropometric data

No.	Subject	Age (yr)	Ht. (cm)	Stem height (cm)	Leg length (cm)	Foot length (cm)
1	DCD	18	181·4	36·1	99·5	26·7
2	JB	18	175·3	36·3	91·6	26·4
3	VT	18	163·3	34·8	84·0	24·4
4	GJJ	18	170·4	35·6	89·5	23·7
5	JEJ	18	175·8	36·3	90·6	27·5
6	JEM	18	168·6	34·8	89·1	25·7
7	BJJ	18	162·5	33·0	85·3	25·3
8	JD	18	171·6	36·8	88·4	25·7
9	EWW	19	161·3	33·7	86·5	24·8
10	JC	18	178·5	37·4	94·4	28·3
11	JDAF	18	170·5	35·6	87·9	26·1

The increase in ventilation with body temperature was calculated from the rest and exercise CO_2 responses, which did not differ significantly, on the assumption (for which there is some evidence—Cotes (1955 a)) that there are no other factors operative during moderate steady state exercise breathing pure O_2.

The change in ventilation between breathing air and O_2 during exercise was measured over the 2nd to 5th min of alternating periods of breathing these two gases. The pulmonary diffusing capacity was measured during the second minute of breathing 0·15 per cent CO in air, a dead space proportional to the body weight being assumed (Bates *et al.* 1955).

The amplitude of vertical oscillation of the body during walking was obtained from the vertical movement of a string attached to the waist and recorded either on a kymograph or on a mechanical integrator (cf. Benedict and Murschhauser 1915). To ensure that the recording string was kept vertical and to limit arm movements the subjects walked between tapes. The amplitude of oscillation (in metres) was multiplied by the step frequency per minute and the body weight (kg) to obtain an estimate of vertical work (kgm/min). This was converted to kilocalories (by division by 427) to facilitate comparison with the measured energy expenditures expressed in these units.

§ 3. Results

3.1. *Presentation of Results*

The results are presented in Tables 2, 3 and 4 and in Fig. 1. Table 2 includes energy expenditure, ventilation equivalent, vertical work done in walking and pulmonary diffusing capacity, for subjects walking at $3\frac{1}{2}$ m.p.h. on up to four occasions. It also includes the following indices calculated from the rest and exercise data: the increase in body temperature per kcal/min increase in energy expenditure; the increase in ventilation per mmHg increase in pCO_2; and the increase in ventilation per 1°C rise in body temperature. The raw data from which these indices were calculated are also available (Cotes 1956).

Table 3 gives the differences in ventilation volume per minute for the subjects walking at $3\frac{1}{2}$ m.p.h. breathing (i) air and (ii) O_2 for alternate five minute periods. Table 4 gives mean values of the indices for subjects on whom complete data are available for two or more days. Changes in some of the indices measured on all four days are illustrated in Fig. 1.

Complete measurements were not obtained on subject 3, who developed foot strain before day 3: data for this subject are not included except for those on the effects of breathing air and 100 per cent O_2 and on the pulmonary diffusing capacity, measurements not completed on subsequent periods. Also incomplete and omitted from Table 4 are data for subject 4 on the effect of breathing 100 per cent O_2 and for subject 10 on the ventilatory response to CO_2 and to body temperature change.

These omissions have the effect of leaving ten subjects in all groups except for diffusing capacity measurements (days 1 and 2) where there are eleven subjects and for the changes in ventilation with pCO_2 and with body temperature change (days 1, 2 and 3) where there are nine.

Table 2. Energy expenditure (EO ; kcal/min), ventilation equivalent (V.E. ; 1/100 ml O_2), vertical work done in walking (W_L ; kcal/min), increase in body temperature per kcal per min increase in energy expenditure (T; °c/kcal/min), pulmonary diffusing capacity (DCO; ml/min/mm Hg), and ventilation increases per mm increase in pCO_2 (V_E/mmpCO_2) and in body temperature (V_E/°c) for subjects walking at $3\frac{1}{2}$ m.p.h. on four occasions

Subject	Day	Body weight (kg)	EO (kcal/min)	V.E. (1/100 ml O_2)	Increase in body temperature per kcal increase in energy expenditure	W_L (kcal/min)	DCO (ml/min/mm Hg)	Regression coefficients: Vent. increase per mm increase in pCO_2	Regression coefficients: Vent. increase per °c increase in body temperature
1	(i)	65·5	4·97	2·60	0·136	0·92	44·2	1·276	24·528
	(ii)	65·8	4·89	2·17	0·102	0·85	34·3	1·719	35·837
	(iii)	67·8	5·62	2·00	0·172	0·70	37·3	4·103	29·029
	(iv)	66·4	4·85	2·45	—	0·78	—	—	—
2	(i)	66·5	5·38	2·00	0·113	0·96	48·4	1·294	26·539
	(ii)	67·0	5·00	2·21	0·172	0·96	44·3	1·243	29·574
	(iii)	66·0	5·35	2·00	0·196	0·80	32·0	1·768	19·180
	(iv)	68·2	4·79	2·21	—	0·79	—	—	—
3	(i)	57·6	4·81	2·37	0·271	0·90	24·8	1·411	13·387
	(ii)	57·3	5·54	2·48	0·294	0·83	31·1	1·554	10·774
	(iii)	—	—	—	—	—	—	—	—
	(iv)	—	—	—	—	—	—	—	—
4	(i)	56·5	5·87	2·32	0·205	1·02	31·1	2·461	14·182
	(ii)	57·0	5·06	2·35	0·299	0·81	19·5	2·359	15·646
	(iii)	59·3	5·08	2·29	0·255	0·89	24·2	4·015	25·818
	(iv)	58·7	5·01	2·68	—	0·54	—	—	—
5	(i)	66·0	5·66	2·45	0·072	1·07	28·2	1·648	18·759
	(ii)	63·8	5·60	2·15	0·105	0·85	33·8	1·706	4·328
	(iii)	63·4	5·39	2·16	0·074	0·71	24·3	3·074	57·298
	(iv)	64·5	4·71	3·12	—	0·52	—	—	—

6	(i)	52·8	4·19	2·34	0·227	0·68	27·7	2·157	12·100
	(ii)	54·5	4·33	2·42	0·233	0·68	31·3	2·007	11·719
	(iii)	55·5	3 97	2·10	0·228	0·57	—	4·109	24·808
	(iv)	54·4	3·87	2·55	—	0·50	—	—	—
7	(i)	51·0	4·31	2·18	0·272	0·62	28·9	1·341	7·381
	(ii)	52·0	4·40	2·13	0·217	0·62	32·9	2·011	19·557
	(iii)	52·8	4·02	2·23	0·247	0·52	25·7	2·589	18·281
	(iv)	52 9	3·85	2·36	—	0·43	—	—	—
8	(i)	52·5	4·34	2·37	0·271	0·85	24·8	1·922	11·847
	(ii)	54·0	4·68	2·48	0·262	0·72	34·5	1·349	6·922
	(iii)	55·5	4·10	2·37	0·247	0·69	22·5	2·053	13·056
	(iv)	55·4	4·01	2·63	—	0·65	—	—	—
9	(i)	62·0	6·02	2·19	0·154	0·99	31·8	1·220	22·314
	(ii)	60·5	5·30	2·17	0·121	0·89	40·7	1·155	38·192
	(iii)	63·0	5·37	2·77	0·123	0·85	21·0	1·951	26·195
	(iv)	61·0	4·86	2·27	—	0·73	—	—	—
10	(i)	72·5	6·12	2·28	0·148	1·06	35·2	2·108	20·036
	(ii)	72·5	6·04	2·22	0·106	0·96	38·3	—	—
	(iii)	72·5	5·73	2·42	0·174	0·87	27·0	1·620	22·806
	(iv)	74·6	5·30	2·48	—	0·90	—	—	—
11	(i)	55·0	5·14	2·23	0·189	0·88	28·5	1·299	26·557
	(ii)	55·5	4·80	2·01	0·301	0·70	29·0	1·977	14·561
	(iii)	57·5	4·55	2·20	0·252	0·69	25·6	1·444	18·125
	(iv)	59·0	4·41	2·37	—	0·62	—	—	—
Mean	(i)	60·0	5·20	2·30	0·179	0·91	32·9	—	—
	(ii)	60·3	5·01	2·23	0·192	0·80	33·9	—	—
	(iii)	61·3	4·92	2·25	0·197	0·73	26·6	—	—
	(iv)	61·5	4·57	2·51	—	0·65	—	—	—

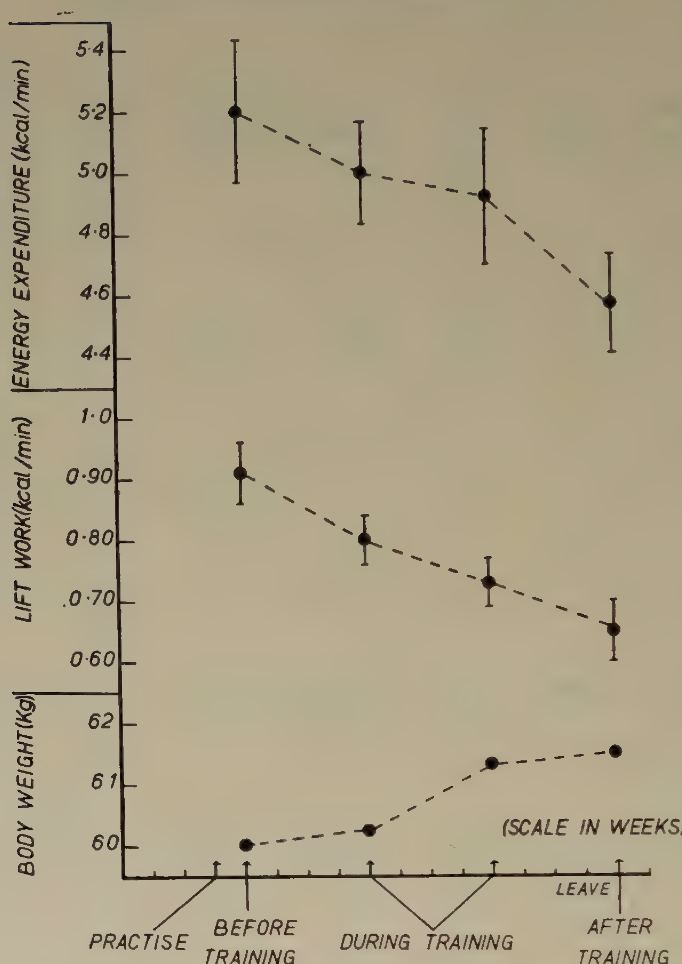


Figure 1. Mean values, with standard errors, for energy expenditure, lift work and body weight of 10 subjects walking at 3½ m.p.h. on four occasions over a period of training.

Table 3. Ventilation volume per minute (l/min) whilst walking at 3½ m.p.h. breathing (i) air and (ii) oxygen

Subject	Day I			Day II			Change between days I and II
	Air	O_2	Diff.	Air	O_2	Diff.	
1	27·6	26·1	+1·5	23·1	24·1	−1·0	+2·5
2	23·0	22·3	+0·7	24·5	23·4	+1·1	−0·4
3	23·0	21·4	+1·6	24·8	24·0	+0·8	+0·8
5	36·0	31·3	+4·7	24·5	23·0	+1·5	+3·2
6	20·7	20·6	+0·1	21·3	21·1	+0·2	−0·1
7	19·3	18·9	+0·4	20·2	19·5	+0·7	−0·3
8	20·8	18·0	+2·8	22·6	20·5	+2·1	+0·7
9	27·3	24·7	+2·6	23·4	23·7	−0·3	+2·9
10	30·0	28·8	+1·2	28·5	28·6	−0·1	+1·3
11	24·2	23·4	+0·8	20·1	18·7	+1·4	−0·6
Mean	25·19	23·55	1·64	23·30	22·66	0·64	1·00
S.E. Diff.			0·439			0·30	0·451

Combined values for these last two indices have also been calculated from data obtained on days 1 and 2. These data analysed with respect to body surface area are available elsewhere (Cotes and Meade 1958).

3.2. *Analysis of Results* (*see Table* 4)

Body weight was found to increase significantly ($p < 0{\cdot}01$) over the training period. The rate of performing vertical work in walking at $3\frac{1}{2}$ m.p.h. on the horizontal treadmill was found to decrease significantly ($p < 0{\cdot}01$) over the four experimental periods from 0·91 (mean value) to 0·65 kcal/min. At the same time the rate of energy expenditure apparently diminished ($p \simeq 0{\cdot}1$) from 5·20 (mean) to 4·57 kcal/min (see Fig. 1).

Thus, over the training period the rate of energy expenditure decreased by an average of 0·63 kcal/min, and the rate of performing vertical work by 0·26 kcal/min. The ratio of these changes is of the same order as that found at the end of training for the subjects walking naturally on the treadmill at a range of speeds. The findings are illustrated in Fig. 2 where the continuous line is the average relationship at speeds of 1–4 m.p.h. obtained independently for the same subjects at the end of the training period. The relationship is

[Energy expenditure $= (3{\cdot}25 \times$ lift work $+ 2{\cdot}4)$kcal/min ($r = 0{\cdot}9$).]

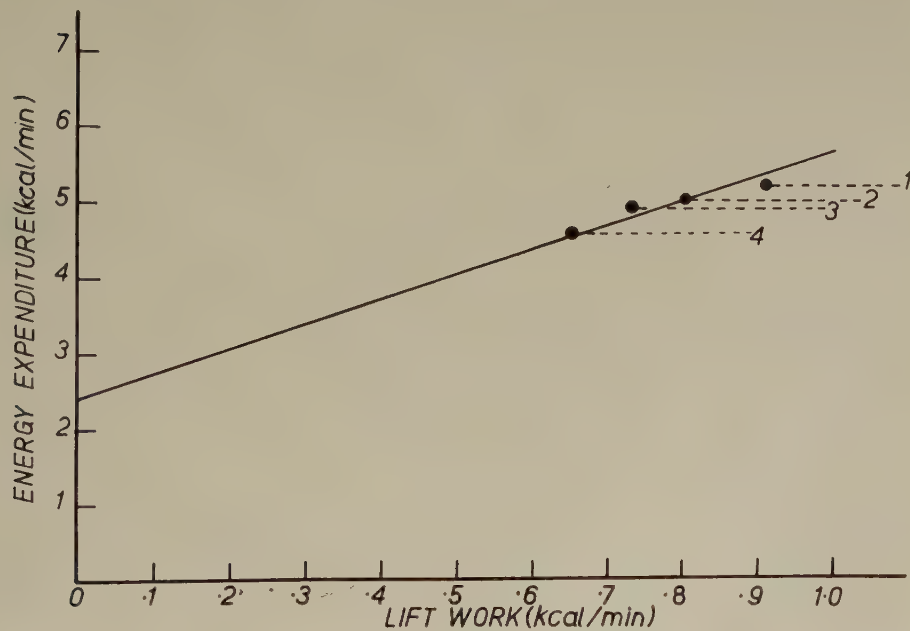


Figure 2. Relationship between energy expenditure and lift work for 10 subjects walking naturally on the flat. Continuous line is average relationship for subjects walking at speeds of 1–4 m.p.h. (lift work 0·03–1·1 kcal/min). Closed circles are mean values at $3\frac{1}{2}$ m.p.h., 1 before, 2 and 3 during and 4 at the end of the physical training period.

The closed circles are the mean values obtained at $3\frac{1}{2}$ m.p.h. on days 1–4 over the training period. They lie along the regression line, showing that the apparent reduction in the energy expenditure of walking at $3\frac{1}{2}$ m.p.h. consequent upon training is closely related to the reduction in vertical work done.

Table 4. Mean values and ranges for measured indices in subjects walking at 3½ m.p.h. before, during and after a physical training programme

	Before training	During training		After training	Level of significance of trend if suggestive
	0	4 weeks	8 weeks	12 weeks	
(*a*) Body weight (kg)	60·0 51·0–72·5	60·3 52·0–72·5	61·3 52·8–72·5	61·5 52·9–74·6	0·01
(*b*) Rate of metabolic energy expenditure (kcal./min)	5·20 4·19–6·12	5·01 4·33–6·04	4·92 3·97–5·73	4·57 3·85–5·30	0·1
(*c*) Rate of performing vertical work in walking (kcal/min)	0·91 0·62–1·07	0·80 0·62–0·96	0·73 0·52–0·89	0·65 0·43–0·90	0·01
(*d*) Ventilation equivalent for oxygen (l/100 ml/min)	2·30 2·00–2·60	2·23 2·01–2·48	2·25 2·00–2·77	2·51 2·21–3·12	–
(*e*) Rise in body temperature on exercise per kcal increase in rate of metabolic energy expenditure °c/kcal/min	0·179 0·072–0·272	0·192 0·102–0·301	0·197 0·074–0·255	–	–
(*f*) Increase in ventilation per unit increase in pCO_2 (l/min/mm Hg)	1·58 1·22–2·46	1·47 1·16–2·36	2·52 1·44–4·11	–	0·057 (overall significance)
(*g*) Increase in ventilation per unit increase in body temperature (l/min/°c)	16·3 7·4–26·6	14·1 4·3–38·2	20·3 13·1–57·3	–	
(*h*) Reduction in exercise ventilation breathing 100 per cent oxygen instead of air (l/min)	1·64 0·1–4·7	0·64 −1·0– +2·1	–	–	0·05
(*i*) Pulmonary diffusing capacity for CO (ml/min/mm Hg)	32·1 24·8–48·4	33·6 19·5–44·3	–	–	–

This represents a reduction in lift per step, since the step frequency per minute did not change significantly.

The two indices, ventilation equivalent for O_2 and rise in body temperature per kcal increase in energy expenditure, did not alter significantly over the training period. Significant differences were present initially between subjects

for increases in ventilation per unit increase in pCO_2 and in body temperature, but no significant changes occurred over the first four weeks of training. However, over the second four weeks statistically significant increases were obtained.

When the data were combined, individual differences being ignored, it was found that on average the ventilation increased by $1{\cdot}8 \pm 0{\cdot}13$ l/min/mm pCO_2 and by $16{\cdot}2 \pm 1{\cdot}41$ l/min/°c rise in body temperature.

Significant differences were found both before training and in the fourth week of training in the reduction in ventilation consequent on switching the inspired gas from air to oxygen during exercise. The changes were significantly less on the second occasion. No differences were found for the pulmonary diffusing capacity for carbon monoxide between estimates made before and during the 4th week of training.

§ 4. Discussion

4.1. *Reduction in Energy Expenditure for a given task with Training*

It is well known that the energy expenditure of a number of activities decreases with training, for example bicycling (Gemmill *et al.* 1930), uphill treadmill walking (Knehr *et al.* 1942) and barrow wheeling (Crowden 1928). Similar changes were found for horizontal treadmill walking in the present investigation; our subjects also gained weight, which is further evidence that training had an effect. The reduction in energy expenditure may be the result either of practice, leading to increased economy of movement on account of better neuro-muscular co-ordination, or of physiological changes leading to less wasteful conversion of chemical to mechanical energy. It has been pointed out (Karpovich 1953) that no controlled study has yet been performed to differentiate between these alternatives.

Differentiation is also possible through the analysis of energy expenditure in relation to our estimated vertical work done. When this is done, with allowance for the energy expenditure on extrapolation to zero work, it is found that the excess energy expenditure and the vertical work decrease in proportion when the subjects repeat the same activity over the training period. Thus the estimate of the ratio of conversion of chemical to mechanical energy remains constant, confirming that the observed changes are the result of increased economy of effort, rather than of increased internal efficiency within the muscles.

These findings suggest that the reduced energy expenditure is a result of practice and that it need not be related to an increase in muscle power though this can also occur.

4.2. *Reduction in Ventilation Volume per minute for a given Oxygen Consumption*

Much of the reduction in ventilation minute volume with training is a consequence of the reduced energy expenditure. However, the ventilation equivalent, which is the ventilation per unit of oxygen consumption, also diminishes with training; conversely it increases after a period of bed rest (Taylor *et al.* 1949). The change with training is largely attributable to decreased anaerobic metabolism and decreased production of lactic acid in the active muscles, due to an improved blood supply to the muscles. However, there are two other possible factors.

First, examination of the literature suggests that the rise in body temperature per unit increase in energy expenditure is less in the athlete than in the non-athlete. Since the rise in temperature is itself a respiratory stimulant (e.g. Bannister *et al.* 1954) this may be a contributing factor. The mechanism would be that the athlete tends to have a higher cardiac output on exercise than the non-athlete (e.g. Bock *et al.* 1928) and so has more blood per minute available for circulation through the skin where heat loss occurs. The converse situation has been shown to exist in patients with reduced cardiac outputs (Donald *et al.* 1955.). Thus, physical training, if it increases the cardiac output per unit oxygen consumption, might diminish the body temperature rise with exercise and so diminish the ventilation. There is however no evidence that an increase in cardiac output does occur with training (e.g. Freedman *et al.* 1955), but few subjects have been investigated.

The second factor concerns the adequacy of saturation of arterial blood and has so far been investigated only indirectly through analysis of the change in ventilation on alteration of the inspired gas between air and 100 per cent O_2 during exercise. This was first done by Briggs (1920) who pointed out that the change in ventilation diminishes with increasing fitness. The method has since been applied to groups of subjects of differing degrees of fitness with and without organic disease (Cotes 1955 b, French *et al.* 1955). It has not hitherto been applied to the same subjects before and after training.

In this investigation the effects of anaerobic metabolism have been eliminated as far as possible by adoption of a low work level, and changes in body temperature responses and in the air/oxygen ventilation difference have been investigated. No change in either the ventilation equivalent or in the rise in body temperature with exercise was obtained. This is to some extent due to the low level of energy expenditure, and consequent smallness of the possible differences, and does not rule out the possibility of the body temperature change playing a part at higher work levels; the negative findings however lend no support to the body temperature hypothesis. Changes in lactic acid liberation, where they occur, are likely to be important at least as factors contributing to the differences in ventilation which take place with training.

The finding that the air/oxygen ventilation differences diminish with training is in accord with Briggs' original observations. The changes were in the direction of reduced air ventilation values as a result of training, but were not sufficient to alter materially the ventilation equivalent. The mechanism is still in doubt. The effect occurs almost instantaneously on switching from breathing air to breathing oxygen (Asmussen and Nielsen 1946, Dejours *et al.* 1957) so it is likely to be related directly to changes in arterial oxygen tension. Thus the tensions are probably higher on exercise breathing air in trained than in untrained subjects though the differences will be small (cf. Asmussen and Nielsen 1957). The higher values may be due to increased uniformity of ventilation and perfusion in the lung, to an increased lung diffusing capacity for oxygen or to a reduced shunt of venous blood across the lungs. The first of these alternatives seems to us most likely whilst the third is improbable. The second, an increased diffusion capacity for oxygen, would be less effective than the others in increasing the arterial oxygen tension under the conditions of study (cf. Lilienthal *et al.* 1946). Furthermore, no increase in the related diffusing capacity for carbon monoxide was obtained.

However, high values have been reported in at least one athletic subject (Bates *et al.* 1955) and in fit subjects (Heinoven *et al.* 1958) and there is need for further investigation along these lines.

The changes in the ventilatory responses to carbon dioxide and to body temperature which we also found in this investigation were unexpected and the mechanisms are uncertain. They could both be the result of an increased ventilatory response to carbon dioxide due to the subjects coming to know the type of response expected of them. This aspect also merits further investigation.

We are indebted to the Army Personnel Research Committee and to our subjects for their cooperation; to Dr. C. G. Warner of the National Coal Board Divisional Laboratory, Ystrad Mynach for the carbon monoxide estimations; to Miss C. Yandle and other members of the Unit staff for valuable assistance; to Mr. P. D. Oldham and Dr. M. E. Wise for the statistical analyses and to Dr. J. C. Gilson (Director, Pneumoconiosis Research Unit) for his help and interest in the investigation.

Chez onze hommes qui faisaient leur service militaire il y eut, pendant leur cours préliminaire d'entraînement, un décroissement dans la dépense d'énergie et dans le ' travail vertical ' pendant la marche à 5·5 km par heure. On attribue ce décroissement à une économie progressive de mouvement puisque la proportion de l'énergie depensée au ' travail ' accompli restait constante. La réduction de la ventilation d'exercice quand on changea le gaz inspiré de l'air à l'oxygène diminue aussi pendant la période d'entraînement, ce qui indiquait une amélioration dans l'oxygénation du sang dans les poumons. Il n'y eut point de changement concurrent dans la capacité pulmonaire de diffusion ni dans l'équivalent ventilatoire. On n'obtint point d'evidence de ces expériences qui soutint l'hypothèse que, à la suite de cet entraînement, la température du corps s'élève moins pendant l'exercice, et que cela contribue aux changements dans la ventilation d'exercice.

Bei 11 Männern des ' National Service ' sanken während ihres Vor-Trainings-Kurses der Energieumsatz und die ' vertikale Arbeit ' beim Gehen mit 5·5 km/h. Das wurde auf einer grösseren Bewegungsökonomie zurückgeführt, da das Verhältnis von Energieaufwand zu geleisteter mechanischer vertikaler Arbeit konstant blieb. Die Abnahme der Arbeitsventilation beim Uebergang von Luft- zu Sauerstoffatmung nahm gleichfalls im Laufe des Trainings ab, vermutlich als Folge einer besseren Sauerstoffsättigung des Blutes in den Lungen. Es fand sich keine übereinstimmende Veränderung in der pulmonaren Diffusions-Kapazität oder im Ventilations-Aquivalent. Es fanden sich keine experimentellen Beweise für die Hypothese, dass als Folge des Trainings die Körpertemperatur bei der Arbeit weniger stieg und dass dadurch die Arbeitsventilation werändert wird.

References

Asmussen, E., and Nielsen, M., 1946, Studies on the regulation of respiration in heavy work. *Acta physiol. scand.*, **12,** 171–188; 1957, Measurement of arterial oxygen tension in light and heavy exercise. *Acta physiol. scand.*, **42,** suppl. 145, 17.

Bannister, R. G., Cunningham, D. J. C., and Douglas, C. G., 1954, The carbon dioxide stimulus to breathing in severe exercise. *J. Physiol.*, **125,** 90–117.

Bates, D. V., Boucot, N. G., and Dormer, A. E., 1955, The pulmonary diffusing capacity in normal subjects. *J. Physiol.*, **129,** 237–252.

Benedict, F. G., and Murschhauser, M., 1915, Energy transformations during horizontal walking. Carnegie Institute of Washington. Report No. 231.

Bock, A. V., Vancaulaert, C., Dill, D. B., Folling, A., and Hurxthal, L. M., 1928, Studies in muscular activity. *J. Physiol.*, **66,** 136–161.

Briggs, H., 1920, Physical exertion. Fitness and breathing, *J. Physiol.*, **54,** 292–318.

Comroe, J. H., 1944, The hypernoea of muscular exercise. *Physiol. Rev.*, **24,** 319–339.

Cotes, J. E., 1955 a, The role of body temperature in controlling ventilation during exercise in one normal subject breathing oxygen. *J. Physiol.*, **129,** 554–563; 1955 b, The role of O_2, CO_2 and lactic acid in the ventilatory response to exercise in patients with mitral stenosis. *Clin. Sci.*, **14,** 317–328; 1956, An investigation of the physiological effects of training. Army Personnel Research Committee Report. 56/28.

Cotes, J. E., and Meade, F., 1958, The ventilatory response to a rise in body temperature in relation to other physiological variables. *J. Physiol.*, **140,** 55–56 P; 1959, The energy expenditure and mechanical energy demand in walking. *Ergonomics* (in the press).

Crowden, G. P., 1928, Physiological cost of the muscular movements involved in barrow work. M.R.C. Industrial Fatigue Research Board. No. 50.

Dejours, P., Girard, F., Labrousse, Y., and Raynaud, J., 1957, Stimulus oxygene chemoreflexe de la ventilation a basse altitude chez l'homme—II. Ancours de l'exercise musculaire. *J. Physiol. Path. gén.*, **49,** 115–124.

Donald, K. W., Bishop, J. M., and Wade, O. L. 1955, Changes in the oxygen content of axillary venous blood during leg exercise in patients with rheumatic heart disease. *Clin. Sci.* **14,** 531–551.

Freedman, M. E., Snider, G. L., Brostoff, P., Kimelblot, S., and Katz, L. N., 1955, Effects of training on response of cardiac output and muscular exercise in athletics. *J. appl. Physiol.*, **8,** 37–47.

French, G. N., McPhaul, M. V., and Melton, R. S., 1955, Some effects of physical training on breathing, oxygen consumption and oxygen extraction during moderate exercise. U.S. Naval School of Aviation Medicine Research Report NM. 001.105.100.02.

Gemmill, C., Booth, W., and Pocock, B., 1930, Muscular Training I. The physiological effect of daily repetition on the same amount of light muscular work. *Amer. J. Physiol.*, **92,** 253–270.

Gray, J. S., 1950, *Pulmonary ventilation and its physiological regulation* (Springfield: Illinois: G. C. Thomas.

Heinoven, A. O., Karvonen, M. J., and Ruosteenoja, R., 1958. Pulmonary diffusing capacity at rest and physical fitness. *J. Physiol.*, **142,** 54–55 P.

Karpovich, P. V., 1953, *Physiology of muscular activity.* (Philadelphia: W. B. Saunders).

Knehr, C. A., Dill, D. B., and Neufeld, W., 1942, Training and its effects on man at rest and work. *Amer. J. Physiol.*, **136,** 148–156.

Lilienthal, J. L., Riley, R. L., Proemmel, D. D., and Franke, R. E., 1946, An experimental analysis in man of the oxygen pressure gradient from alveolar air to arterial blood during rest and exercise at sea level and at altitude. *Amer. J. Physiol.*, **147,** 199–216.

Mead, J., and Bonmarito, C. L., 1949, Reliability of rectal temperatures as an index of internal body temperature. *J. appl. Physiol.*, **2,** 97–109.

Rahn, H., and Otis, A. B., 1949, Continuous analysis of alveolar gas composition, during work, hyperpnoea, hypercapnia and anoxia. *J. appl. Physiol.*, **1,** 717–724.

Scholander, P. F., 1947, Analyzer for accurate estimation of respiratory cases in one half cubic centimetre samples. *J. biol. Chem.*, **167,** 235–250.

Taylor, H. L., Henschel, A., Brozek, J., and Keys, A., 1949, Effects of bed rest on cardiovascular function and work performance. *J. appl. Physiol.*, **2,** 223–239.

PROBLEMS OF TRAINING OF THE CARDIOVASCULAR SYSTEM

By M. J. Karvonen

Institute of Occupational Health, Helsinki, Finland

Training of the cardiovascular system may effect several structural, chemical and functional changes. Some of the functional changes become manifest only during exercise, others are observable also at rest. To some extent changes due to training are independent of each other, and depend on the type of training. For example, a decrease of the pulse rate during standard exercise is obtained only by training at high pulse rate levels.

Training may reduce the mechanical work of the heart at rest. It increases the performance capacity of strenuous exercise. In submaximal work it may reduce the effort needed.

Training of the cardiovascular system is not known to produce detrimental effects on health. The longevity of trained athletes is equal to or even longer than that of other comparable groups. The serum cholesterol level of athletes in training may be lower than that of the general population. In women, signs of a trained cardiovascular system are associated with reduced incidence of premature births.

Training of the cardiovascular system has much to recommend it because of its effects on performance capacity and health.

§ 1. Changes in Physiological Functions

The cardiovascular system may be considered trained when it is well adapted to some particular functional requirement. The most common requirement is that of an increased cardiac output. If a man or woman can develop a large cardiac output, and with the aid of it a high maximum oxygen uptake, his or her cardiovascular system must be regarded as trained.

In order to achieve a large cardiac output, structural, chemical and functional adaptations are used. Perhaps the most important among the structural adaptations is an increase of the total blood volume (Kjellberg *et al.* 1949 a, b). Of the functional adaptations most become manifest only during exercise, but there are some which are observed also at rest. Well-known examples of functional adaptations observable at rest are an increased heart volume (Kjellberg *et al.* 1949 a, b, Karvonen *et al.* 1957 b) and often but not always a slow resting pulse rate. Recently described functional adaptations at rest are changes in the voltage and in the angles of the spatial vector electrocardiogram, opposite to those seen with ageing (Rautaharju and Harjola 1957), and an increase of the diffusion capacity of the lungs (Heinonen *et al.* 1958).

The pulse rate measured at rest, during standard exercise, and during recovery from exercise, has been used much for the assessment of the training—or ‘ fitness ’—of the cardiovascular system. Stepping on a bench (a laboratory form of stair climbing) and work on a bicycle ergometer have often been employed as forms of standard exercise. Ryhming (1953, 1958) has reported a comparison between these two tests. When the pulse rate is determined during work, the various forms of exercise tests can be made closely comparable with each other. The pulse rate determined $1–1\frac{1}{2}$ min after work is also significantly correlated with the rate during work.

Niemi (1954) has made an extensive comparison of bicycle ergometer and step tests. In the ergometer test, loads of 5, 10, 15 and 20 kgm/sec were

used for 4 min each. The step test lasted 2 min, and was made using a step of height 45 cm, at rates of 12, 18, 24, 30 and 36 steps/min. In the ergometer test, the pulse rate was counted every 30 sec during the work. The variables taken into account were

A. RP = Resting pulse rate.

B. *Ergometer test*

MP = Maximum pulse rate attained during work.

PI = Pulse rate increase from resting value to maximum value attained during work.

PIW = Pulse rate increase during work.

RecP 2′ = Recovery pulse rate above resting rate at 2–2½ min.

RecP 5′ = Recovery pulse rate above resting rate at 5–5½ min.

C. *Step test*

ST = Pulse rate from 10 sec to 2 min 10 sec immediately at the end of the step test.

All possible correlations between these values were calculated.

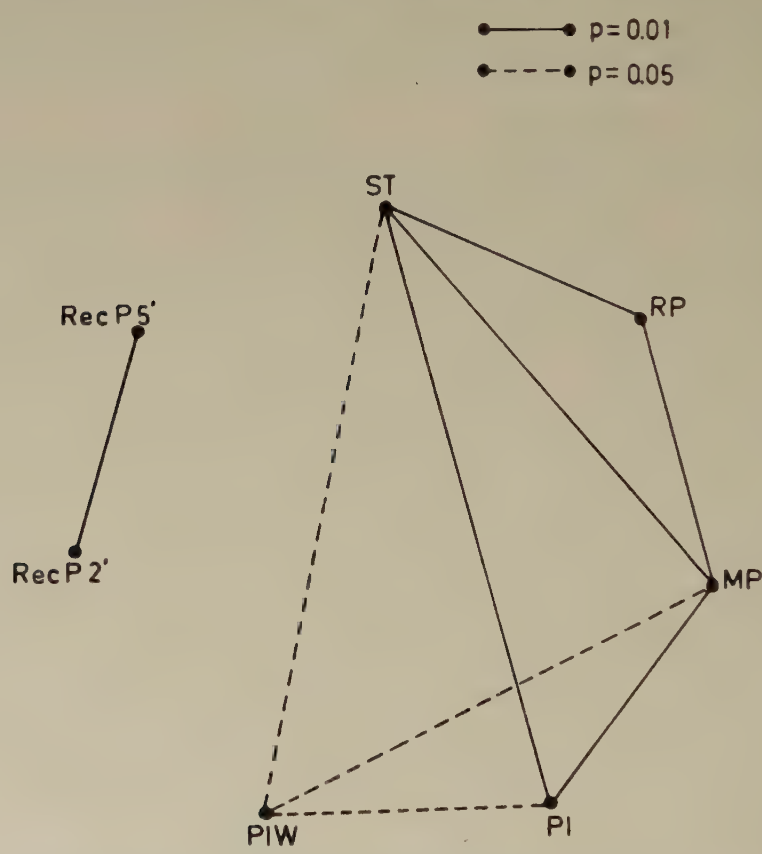


Figure 1. Diagram to illustrate the correlations between pulse rate after step test (ST), resting pulse rate (RP), maximum pulse rate during ergometer work (MP), increase of pulse rate from resting level to level during ergometer work (PI), increase of pulse rate during work (PIW), and recovery pulse rates (RecP 2′ and RecP 5′) The full lines indicate a correlation significant at the 1 per cent level; the broken lines a correlation significant at the 5 per cent level (after Niemi, 1954).

Figure 1 is a condensation of the information obtained. The step test pulse rate was correlated ($p = 0{\cdot}01$) with resting pulse rate, with maximum pulse rate at each ergometer load, and with the increase of the pulse rate from rest to work. The increase of the pulse rate during the actual work showed correlations ($p = 0{\cdot}05$) with step test pulse rate, with maximum pulse rate, and with the pulse rate increase from rest to work. The recovery pulse rates after the ergometer test were correlated only with each other.

The results displayed in Fig. 1 suggest that the pulse rate differences occurring in the above variables indicate different things. Measures like resting pulse rate and speed of recovery are probably related to the training of the cardiovascular system but they measure different effects of training from what is measured by the increase of pulse from rest to work. The general conclusion may be drawn that training of the cardiovascular system involves several mutually independent mechanisms.

Adaptation may also occur in the circulation time at rest. In the series of 40 Finnish champion atheletes studied by Pere (1948), one third had blood circulation times from elbow to tongue which were slower than normal. The largest deviation from the normal values of 12–18 sec was some 60 sec. Mellerowicz (1953, 1956) has confirmed the prolongation of circulation time in trained subjects. The prolongation is not solely ascribable to an increased total blood volume, but suggests a reduced cardiac output at rest. Calculations of the cardiac output at rest, determined from pulse rate, blood pressure and the velocity of the pulse wave (Mellerowicz 1956) support this conclusion. A decrease of the resting cardiac output as a consequence of training suggests that some adaptation has also occurred extracardially in trained subjects ; the peripheral tissues must take up more of the oxygen supplied in arterial blood. This effect of training has not yet been satisfactorily studied.

§ 2. How the Cardiovascular System becomes Trained

When top representatives of different sports events are examined, the cardiovascular system may show considerable variations. The x-ray determination of the resting heart size gives a good idea of the range observed (Fig. 2). Two explanations may be offered : either people with large hearts are attracted to and succeed in certain sports, or the participation in these events especially increases the heart size. As to the importance of the first of these alternatives, selection, assumptions only may be offered. On the other hand, an increase of heart size has definitely been shown to occur during a training programme (Prokop 1952). The conclusion may thus be drawn that certain—but not all—types of sports training are able to increase the size of the heart.

The effect of different training schedules on the pulse rate during work were studied in a ‘ longitudinal ’ training experiment (Karvonen *et al.* 1957 a). Previously untrained medical students ran on a treadmill, half an hour daily, 4–5 days a week, during four weeks. The speed of the treadmill was adjusted to keep the pulse rate during running at a predetermined level. If the pulse rate tended to decrease as a result of training, the speed of the treadmill was increased. Only in experiments with rather high pulse rates during running did a speeding up of the treadmill become necessary. If the pulse rate during

running was increased by less than 60 per cent of the range available from the resting rate to the maximum obtainable by running, i.e. to less than approx. 135/min, no training effect on the heart rate during running was observed. When training was carried out at a pulse rate of more than 150/min, the heart rate during work did, however, clearly decrease. Evidently a considerable

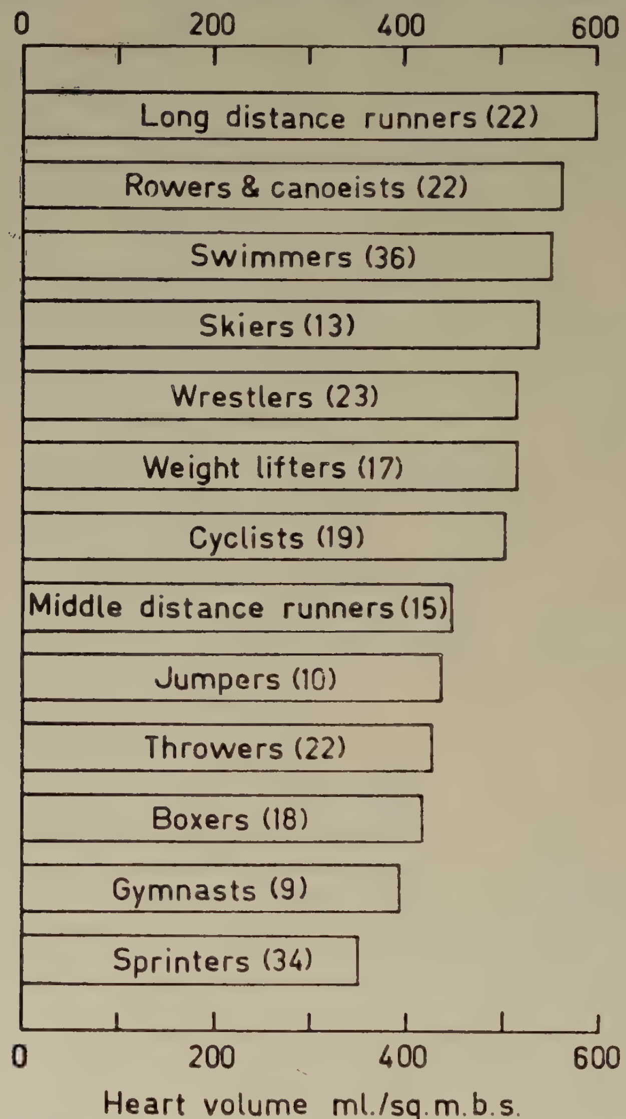


Figure 2. Heart volume of top class Finnish athletes expressed as millilitres per square metre body surface (ml/sq. m.b.s.). Data from Pere (1948), recalculated, and from Karvonen *et al.* (1957 a).

time and effort can be spent in training, without, however, necessarily gaining one of the major effects of training on the cardiovascular system. Nevertheless, the time spent may not be considered as entirely wasted, since other effects of training ensue : slowing of the resting pulse rate ; more rapid recovery after running ; and improvement of the subjective exercise tolerance.

The necessity to train at a high pulse rate in order to produce the full effects of training is a consideration of particular importance in occupational work. In the rationalisation of work, there is a tendency to eliminate peak loads from heavy manual work, for the obvious reason that long rest pauses are needed after high loading, so as to enable physiological functions to return to the original level. Pulse rates above 125/min are considered to exceed the maximum recommended for continuous work (Christensen 1953), and they are now rarely seen in industrial work. However, the elimination of peak loads may in the long run decrease the cardiovascular 'fitness' of manual workers.

§ 3. Benefits of Training

3.1. *At Rest*

The aim of training is to make the organism better adapted to exercise. Correspondingly, the hypothesis might be presented that lack of training makes man better adapted to rest.

Mellerowicz (1956) has presented calculations which suggest that the heart of a trained person does less mechanical work than the heart of an untrained one. At rest, the amount of work done by a trained heart was estimated to be from one half to two thirds of that done by the heart of average men. If the saving of mechanical work is considered an advantage, a resting individual may thus also manifest the beneficial effects of training.

3.2. *In Exercise*

The advantage of a trained cardiovascular system is obvious in performances requiring maximum or near-maximum cardiac output. Such performances occur in sport, in military operations and in a few occupations, like forestry. The higher the maximum cardiac output of a person, the greater evidently will be his working capacity in strenuous exercise.

In work at a submaximal level, at which the functional capacity of the cardiovascular system does not limit the work output, the advantages of a trained condition remain a personal affair. When two men work at the same energy expenditure level, the one having the slower pulse rate is generally considered to do his work with less effort. This concept appears plausible, but has not yet been empirically validated.

Special types of work may occur in which a trained cardiovascular system may be of value, even at relatively low energy expenditure levels. Work in hot environments involves a marked increase of skin blood flow, and thus taxes both the total blood volume and the cardiac output. It appears likely that a person with a large blood volume, and capable of achieving a large cardiac output, would be in a relatively favourable position for work in hot conditions. An eventual increase of heat tolerance resulting from 'unspecific' training of the cardiovascular system would merit a special study.

The effect of training of the cardiovascular system on a very special type of work, flying under acceleratory forces, is a controversial issue. It has been claimed that in experiments with the human centrifuge, subjects with a trained cardiovascular system show a tolerance to radial acceleration in the direction

head→feet below average (Bjurstedt and Ström 1957). However, many of those having practical experience as fighter pilots are of a contrary opinion. The problem requires further study, probably also under more 'realistic' conditions than in the human centrifuge.

On the other hand, success in flight training appears to be positively correlated with performance in various sports, notably in sports requiring training of the cardiovascular system, like a 5000 metres run (Nolin 1954).

3.3. *Training and Health*

The functional capacity of the cardiovascular system may in certain situations become critical for the organism. Pregnancy is one of these critical situations. Recent studies by Räihä *et al.* (1957, and personal communication) suggest that the functional capacity of the mother's circulation—as measured by the x-ray determined volume of the heart—appears to bear a definite relation to the incidence of prematurity. Mothers with a heart size below 320 ml per sq. m. per body surface have four times higher incidence of prematurity than mothers with larger hearts. One practical conclusion from this work would be to determine, whether women's sport or other suitable training programmes will be able to reduce the incidence of prematurity.

Another critical situation comes to the majority of people at the end of life : cardiovascular disease is the principal cause of death in Great Britain, in Finland, and in many other countries. Studies by Morris and his co-workers in Britain (Morris and Heady, 1953, Morris *et al.* 1953) have demonstrated that mortality in cardiovascular disease is less in physically active than in sedentary occupations. A study conducted in America (Morris 1957) has given a comparable result : though farmers, whose occupation still involves much strenuous work, develop clinical manifestations of cardiovascular disease at the same age as the general male population, they die from cardiovascular disease at approximately 10 years more advanced age than the general population.

The conclusion has been drawn that physical work is a positive health factor protecting from or delaying death due to cardiovascular disease. However, those findings do not in any way prove that training of the cardiovascular system is the factor responsible for the protection.

Many athletes submit themselves to more intense training than occurs in any occupational work. On the other hand, the period of years during which athletics or sport is practised remains quite short. It was shown by Rook (1954) that there is no essential difference in the longevity of athletic and non-athletic students, both in British and American Universities. This does not, however, prove that training of the cardiovascular system is necessarily without effect on longevity.

Further light on the problem of training and longevity may be obtained from the length of life of such sportsmen who practice their sport over a longer time than university students generally do. Skiing is such a sport. It is highly effective in training the cardiovascular system (cf. Åstrand 1955). It is practised seriously over many years ; the mean age of the best skiers in long distance races is 30 years, and skiers more than 40 years old have qualified among the best in important competitions (Karvonen 1955). Skiing also easily

remains as a hobby after the years of active competition. An enquiry was sent to champion skiers from years before 1930, asking them how many kilometres they had skied during the winters 1955–56 and 1956–57 : 90 answers were obtained. Of the men, 70 still skied every winter, 35 travelling more than 100 kilometres a year. Many ex-champions continue to ski up to an advanced age.

Information for longevity study was obtained from 388 skiers of whom 157 were still alive and 231 had died. The results are shown in Fig. 3, with three sets of data for comparison. In the groups to be compared, the starting point is the age of 15 years.

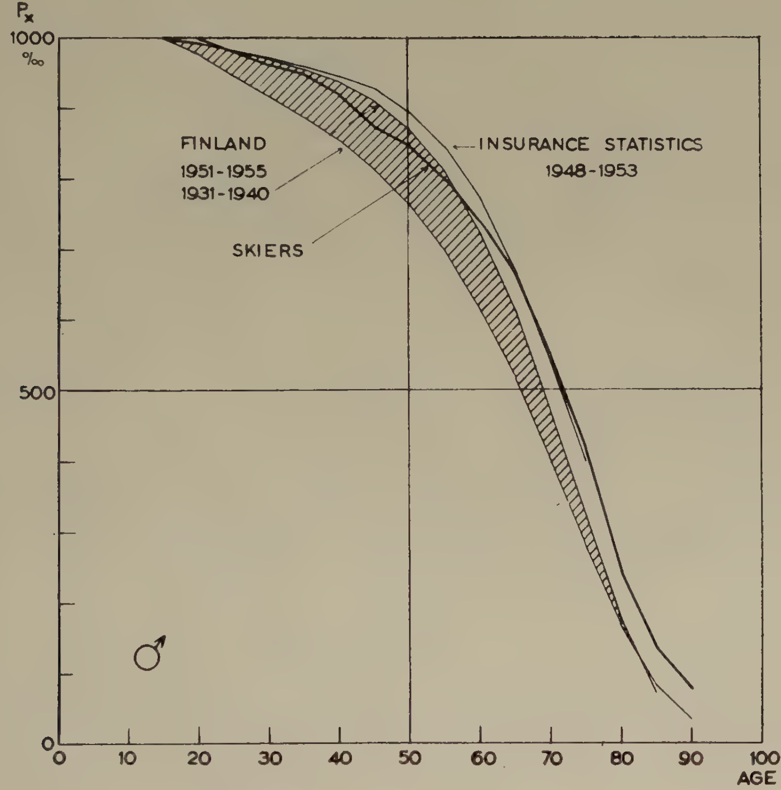


Figure 3. The survival of Finnish champion skiers, as compared with that of Finnish men after the age of 15 years, (*a*) in 1931–1940, (*b*) in 1951–1955, and (*c*) of the male life insurance population in 1949–1953 (Karvonen *et al.* 1958 a).

The probable age of a skier in this material is 72 years. The deaths of the skiers have occurred over a period extending from 1893 to 1957, with the median at 1940. The skiers had a 6–7 years' longer life expectation than the general male population in 1931–40. However, the mean expectation of life in Finland is rapidly increasing, and the differences are much smaller in 1951–55. In many spontaneously selected groups, life tends to be longer than among the general population. The third comparison is a spontaneously selected group, those having taken a life insurance policy. Their longevity is rather close to that of the skiers (Karvonen *et al.* 1958 a).

The conclusion may be drawn from the longevity studies that training of the cardiovascular system over a period of several years does not appreciably shorten the life, but may even prolong it.

The *serum cholesterol level* shows a statistical association with the occurrence of certain types of cardiovascular disease, notably with coronary thrombosis. As to cholesterol, trained athletes like skiers are in a better position than non-trained subjects : the serum cholesterol of both male and female skiers is lower than that of the general population (Karvonen *et al.* 1958 b).

§ 4. Conclusions

1. It is possible to effect several changes in the cardiovascular system through training. To some extent these changes are independent of each other, and depend on the type of training. In order to attain all major effects of training, it is necessary to train at high pulse rate levels.

2. A trained cardiovascular system offers several advantages. In strenuous exercise, the functional capacity is increased. In lighter exercise, the subjective effort needed for performing a task probably is reduced. Even at rest, the mechanical work done by the heart may be less in a trained than in an untrained individual.

3. An increased incidence of premature births is associated with a small, untrained heart.

4. The serum cholesterol level is lower in trained subjects than in the general population.

5. Training does not shorten the life but may even prolong it.

6. Sports and other programmes or activity which lead to training of the cardiovascular system deserve to be regarded as ' preventive rehabilitation '. There is no evidence to support an attitude of caution and reserve in regard to the training of the cardiovascular system.

L'entraînement du système cardiovasculaire peut effecture plusieurs changements chimiques, fonctionnels ou de structure. Quelquesuns des changements fonctionnels ne deviennent manifestes que pendant l'exercice, d'autres peuvent être observés aussi à l'état de repos. A un certain degré les changements dus à l'éntrainement sont sans rapport entre eux et dépendent du genre d'entraînement. Par exemple, un décroissement dans la fréquence du pouls pendant l'exercice de règle est obtenu seulement par l'entraînement à de hauts niveaux de fréquence de pouls.

L'entraînement peut réduire le travail mécanique de coeur en repos. Il augmente la capacité d'accomplir l'exercice fatigante. Dans le travail moins exigeant il peut réduire l'effort nécessaire.

L'entraînement du système cardiovasculaire n'a pas d'effets délétères pour la santé générale. La longévité des athlètes pleinement entraînés est égale à celle d'autres groupes comparables et même en certains cas meilleure. Le niveau de serum-cholesterol chez les athlètes dans l'entraînement peut être plus bas que chez la population en général. Chez les femmes, les signes d'un systèm cardiovasculaire entraîné se trouvent associés à une diminution dans le nombre de couches prematurées.

L'entraînement du systèmo cardiovasculaire se recommande à cause de ses effets pour la capacitè de rendement et pour la santè.

Das Training des kardio-vaskulären Systems kann zu verschiedenen morphologischen, chemischen und funktionellen Aenderungen führen. Einige der funktionellen Aenderungen werden nur während Arbeit sichtbar, andere sind schon bei Ruhe zu beobachten. Zu einem grossen Ausmass sind trainingsbedingte Aenderungen voneinander unabhängig und hängen von der Trainingsweise ab. Eine Abnahme der Pulsfrequenz bei Standardarbeit ist nur bei Training mit hoher Pulsfrequenz zu erreichen.

Training kann die mechanische Arbeit des Herzens bei Ruhe herabsetzen. Es vergrössert die Leistungsfähigkeit für anstrengende Arbeit. Bei submaximaler Arbeit kann es die nötige Anstrengung vermindern.

Es ist nicht bekannt, dass Training des Herz-Gefäss-Systems die Gesundheit schädigt. Die Lebensdauer trainierter Sportler ist gleich gross oder sogar länger als die anderer vergleichbarer Gruppen. Der Serum-Cholesterin-Spiegel von Sportlern beim Training kann niedriger liegen als bei der Gesamtbevölkerung. Bei Frauen findet man bei trainiertem Herz-Gefäss-System ein selteneres Vorkommen von Frühgeburten. Ein Training des Herz-Gefäss-Systems verdient wegen seiner günstigen Wirkungen auf Leistungsfähigkeit und Gesundheit empfohlen zu werden.

References

Åstrand, P.-O., 1955, New records in human power. *Nature, Lond.*, **176**, 922.

Bjurstedt, H., and Ström, G., 1957, ECG and pulse rate responses to prolonged gravitational stress. Paper presented at the 2nd European Congress of Aviation Medicine, Stockholm.

Christensen, E. H., 1953, Physiological valuation of work in the Nykroppa iron works. In *Symposium on Fatigue* (ed. by W. F. Floyd and A. T. Welford) (London: H. K. Lewis), 93–108.

Heinonen, A. O., Karvonen, M. J., and Ruosteenoja, R., 1958, Pulmonary diffusing capacity and physical fitness. *J. Physiol.*, **142**, 54–55 P.

Karvonen, M. J., 1955, Age and performance in athletics. *Arbeitsphysiologie*, **16**, 110–119.

Karvonen, M. J., Kentala, E., and Mustala, O., 1957 a, The effects of training on heart rate. A 'longitudinal' study. *Ann. Med. Exper. Fenn.*, **35**, 307–315.

Karvonen, J., Rautaharju, P., M.Rikkonen. P., and Ruosteenoja, R., 1957 b, Heart size of champion skiers. *Ann. Med. intrrn. Fenn.*, **46**, 169–178.

Karvonen, M. J., Kihlberg, J., Klemola, H., and Virkajärvi, J., 1958 a, Longevity of champion skiers (to be published).

Karvonen, M. J., Rautanen, Y., Rikkonen, P., and Kihlberg, J., 1958 b, Serum cholesterol of male and female champion skiers. *Ann. Med. intern. Fenn.*, **47**, 75–82.

Kejllberg, S. R., Rudhe, U., and Sjöstrand, T., 1949 a, The amount of hemoglobin and the blood volume in relation to the pulse rate and cardiac volume during rest. *Acta physiol. Scand.*, **18**, 136–145; 1949 b, The amount of hemoglobin (blood volume) in relation to the pulse rate and heart volume during work. *Ibid.*, **19**, 152–168.

Mellerowicz, H., 1953, Results of sodium succinate tests for determining the circulation time in trained sports students and champions of a high circulatory efficiency. *Sport Medicine*, ed. by M. J. Karvonen, (Helsinki: Finnish Association of Sports Medicine), 161–162; 1956, Vergleichende Untersuchungen über das Ökonomieprinzip in Arbeit und Leistung des trainierten Kreislaufs und seine Bedeutung für die präventive und rehabilitative Medizin. *Arch. Kreislaufforsch.*, **24**, 70–176.

Morris, J. N., and Heady, J. A., 1953, Mortality in relation to the physical activity of work. *Brit. J. industr. Med.*, **10**, 245–254.

Morris, J. N., Heady, J. A., Raffle, P. A., Roberts, C. G., and Parks, J. W., 1953, Coronary heart disease and physical activity of work. *Lancet*, **265**, 1053–1057, 1111–1120.

Morris, W. H. M., 1957, Coronary atherosclerosis among farmers. Paper presented at the First Wisconsin Conference on Work and the Heart, Marquette University, Milwaukee.

Niemi, M., 1954, Comparison of two types of exercise-pulse rate tests. Paper presented at the XI International Congress of Industrial Medicine, Naples.

Nolin, I., 1954, Samband mellan gymnastiklärarens och flyglärarens betyg. *Medd. Flyg- och Navalmedicinska Nämnden*, No. 4, 16–20.

Pere, S., 1948, Clinical observations on leading Finnish athletes. (In Finnish.) *Duodecim*, **64**, 388–418.

Prokop, L., 1952, *Die Wirkung sportlichen Trainings auf der menschlichen Organismus* (Vienna).

Räihä, C.-E., Johanson, C. E., Lind, J., Kihlberg, J., Backman, A., and Vara, P., 1957, On the weight of new-born children. (In Swedish.) *Finska Läk.Sälsk. Handl.*, **100**, 167–179.

Rautaharju, P., and Harjola, P., 1957, " High voltage electrocardiogram " caused by vigorous training. *Proceedings of the XII International Congress on Occupational Health*, (Helsinki). Vol. III, 431–433.

Rook, A., 1954, An investigation into the longevity of Cambridge sportsmen. *Brit. med. J.*, **1**, 773–777.

Ryhming, I., 1953, A modified Harvard step test for the evaluation of physical fitness. *Arbeitsphysiologie*, **15**, 235–250; 1958, Physiological methods for estimating the physical work capacity in workers especially of the older age groups. *Ergonomics*, **1**, 129–136.

TRAINING MUSCLE STRENGTH

By E. A. Müller

Max-Planck-Institut für Arbeitsphysiologie, Dortmund, Germany

The strength of muscles is adapted to needs by muscular growth. The stimulus for increase in muscle strength is not fatigue but the force exerted during the job. When this force exceeds one-third of maximum strength, the maximum speed of increase in strength is reached with one single, short duration static contraction per day. With one single, short duration contraction per week the rate is one-third of this maximum. Loss of strength after training by daily contraction is at the rate at which it was gained. The slower increase by weekly training leads to a more permanent acquisition of strength. To avoid fatigue in static work the muscles should be trained against a force about double the highest static force which occurs during the job.

Inactivity lowers strength about 30 per cent in a week, with an equally quick return to normal strength by new activity. Atrophy can be prevented by one contraction per day with a force one-fifth of maximal strength. Normal strength is maintained by contractions lying between one-fifth and one-third of maximum strength. The ability of muscles to increase maximum strength varies from muscle to muscle and from person to person. For men it is maximal at 25 years of age and half maximal at ages 10 and 60 years. The rate of increase in men is double that of women at age 25 years and 25 per cent higher at ages 10 and 60 years. This trainability has a minimum in winter and a maximum in summer. It reacts positively on exposure to ultra-violet radiation. It is not improved by a high protein diet but is reduced by a low protein diet.

§ 1. Introduction

Muscular strength increases and decreases with muscular activity and inactivity. The increase of strength with activity is an automatic adaptation to the needs of the job. The decrease with inactivity or low activity is probably due to the economic principle of reducing muscle fibre-mass to the real needs. Muscular strength and muscle fibre-mass are strictly correlated. To keep up an unnecessarily high muscular mass would be costly in metabolism and circulatory effort. Adaptation of muscular strength to the outside demands of force by growth of muscle mass is termed ' muscular training ' and the loss of normal muscle strength and mass by inactivity ' atrophy '. In this brief review, the rate of increase of muscle strength brought about by various training procedures will be discussed.

§ 2. Critical Stimulus for Increase of Muscle Strength

The stimulus necessary for an increase of muscle strength is an increase in the tension over that previously exerted (Siebert 1928). This means that even years of heavy work for many hours per day does not change muscular strength if the maximal tension reached during work remains the same. The threshold values of stimulus necessary for increase of muscle strength were investigated by Müller and Hettinger and have been reported in a number of papers (Hettinger 1953, 1955 a, b, 1958, Hettinger and Müller 1953, 1955, Müller 1957, Müller and Hettinger 1953, 1954, 1956). They showed that the rate of increase in strength due to training is already maximal with one single muscle contraction per day, provided the strength of the training contraction is more than one-third maximum. The contraction may be isometric (no shortening of the

muscle) and last as short a time as possible (Hettinger and Müller 1953). A more elaborate study (Müller and Hettinger 1953) in which the intervals between successive training contractions were varied from a fortnight down to fractions of a day, showed that even with seven contractions per day there was no more rapid increase in strength than with one contraction per day. With intervals longer than one day the rate of increase of strength is reduced and becomes zero with intervals of two weeks. With a one-week interval strength still increases at about one-third of the speed found with a one-day interval (Fig. 1).

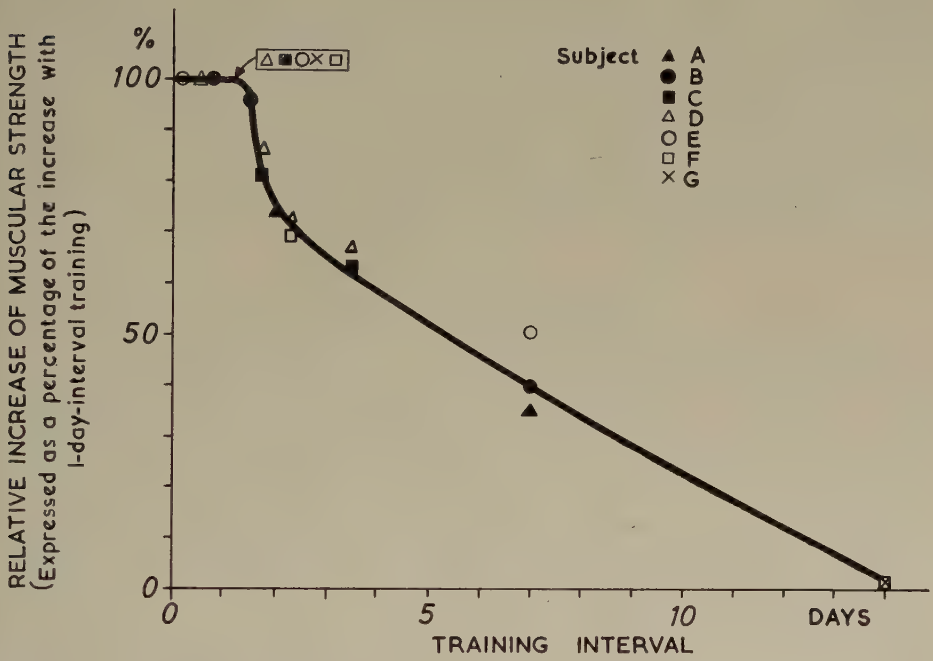


Figure 1. Increase of muscular strength in relation to the interval between two training contractions.

Repeated contractions with a certain fraction of maximal strength, or maximal strength itself, as the training stimulus, led to what was called 'progressive training' by Hellebrandt *et al.* (1947). In the adaptation of muscular strength to a new job, however, which constantly demands forces surpassing one-third of maximum strength, the absolute value of the stimulus remains constant. The value of the stimulus relative to maximum strength falls therefore as the maximal strength increases. When it becomes one-third of the latter, the stimulus loses its character as a critical stimulus.

In progressive training procedures, however, the stimulus is kept above the critical level by increase in proportion to the increase in maximum strength. The automatic adaptation of strength as a result of the force demanded in the job has an endpoint which still permits fatigue to occur. The increase in muscle strength is not influenced by fatigue (Hettinger 1955 b). The muscular blood supply, however, becomes much better by training with work which induces fatigue. But there are limits to improving blood supply and endurance

for heavy work, because blood supply is limited by the tension within the muscle.

As shown by Barcroft and Dornhorst (quoted from Barcroft and Swan 1952), isometric contractions of more than about 15 per cent of the maximal tension prevent muscle blood flow. The tension produced inside a muscle contracting against a given outside force can only be lowered by an increase of muscular strength. If a practical job demands, therefore, a static fatiguing isometric contraction from 0·15 to 0·3 maximal strength, this would not increase muscular strength by training. The training stimulus would be too low (less than 0·3 maximal). If, however, muscle strength could be doubled by training against more than 0·3 maximal strength, the tension within the muscle during the job would be halved and would remain therefore under 0·15 maximal. This would provide the muscle with sufficient blood.

This suggests that many instances of industrial fatigue could be avoided by the training of the muscle doing the job. Such training could be achieved by one single maximal contraction per week of the muscle used in the job, would occupy very little time and result in very little strain.

§ 3. Atrophy of Muscle

Very little activity is necessary to prevent the loss of contractile power of a muscle. While strict inactivity may decrease strength about 30 per cent in a week, one isometric contraction per day, of the shortest duration, at one-fifth of maximal strength, is sufficient to maintain normal strength (Müller and Hettinger 1953, Hettinger 1955 a). When the tension reached in normal life varies between zero and one-fifth maximal, the muscle is in an atrophic state.

Many people have atrophic muscles, due to a sedentary life with lack of activity. The expression ' normal strength ' of a muscle used above is defined as the state of a muscle in which a force stimulus between one-fifth and one-third maximal, having no effect on its strength, is regularly encountered. The table shows the effect of a given force-stimulus (expressed as a percentage of maximum strength) on the maximum strength of the muscle.

	Effect on maximum strength		
Present state of muscle	Training force as percentage of maximum strength		
	<20 per cent	20–35 per cent	>35 per cent
Atrophic	Decreases	Increases	Increases
Normal	Decreases	Remains constant	Increases
After intensive training period	Decreases	Decreases	Increases

§ 4. Maintenance of Strength

The rate of change of muscle strength during and after training a muscle of normal strength can be altered by the course of training (Müller and Hettinger 1954). The curves of Fig. 2 give the percentage increase of strength during training (left of abscissa zero line) and the decrease after training (right of

abscissa zero line) over a period of time up to 100 weeks for three experiments with the following training routines :

(i) Daily training.
(ii) Weekly training.
(iii) Daily training followed by weekly training.

The rate of increase of strength on the daily routine was about three times that on the weekly routine. After training on the daily routine, strength was lost about as quickly as it was gained. In the other experiments the strength gained by training was lost very slowly, 50 per cent of the strength reached at the end of training still being found one year later.

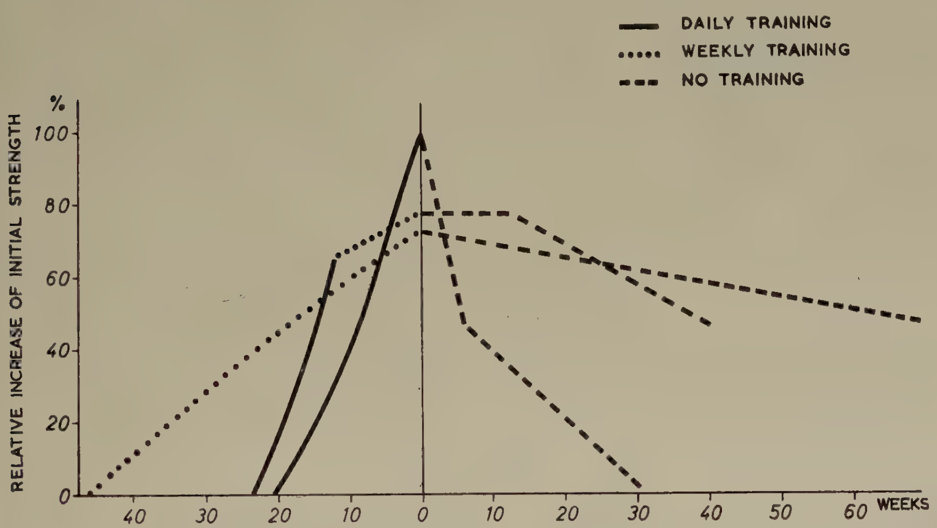


Figure 2. Increase and loss of muscular strength occurring in experiments with different training intervals.

There are thus two ways to get near to a permanent increase in muscle strength : either long-interval training, e.g. training with one contraction per week, or short-interval training followed by maintenance of the trained state through weekly or fortnightly repetitions of one contraction. This is why a workman trained for heavy work does not lose much strength when he interrupts his work for several weeks, and why he tends to remain a stronger man even in his older days.

For a physiological explanation, one could assume that in short-interval training muscles increase the cross section of their fibres, whereas in long-interval training the fibres multiply as well, a change which needs more time and cannot disappear again. The process of multiplying the fibres produces more connective tissues inside the muscle per unit of cross section. This increases the solidity of the muscle.

§ 5. Rate of Increase in Strength

The rate of increase of strength has already been considered as far as it depends on the interval between two training contractions. It depends also on inherent individual factors and on environmental factors,

It is not the same for different muscles of the same person ; sex and age also have a marked influence (Ufland 1934, Schochrin 1935, Hettinger 1953, 1958). Figure 3 shows that the mean strength, as a percentage of the maximum strength of men, is about equal for boys and girls up to 10 years of age. Both

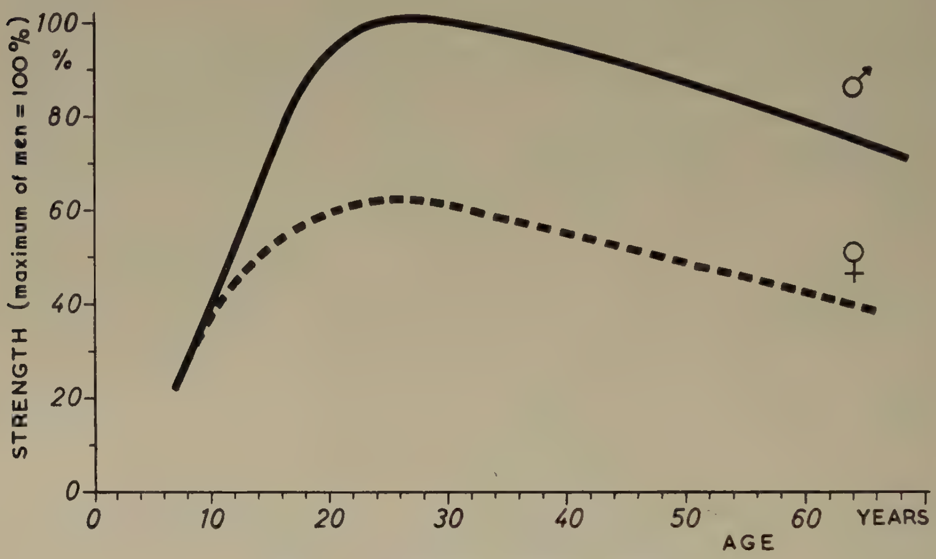


Figure 3. Strength in relation to age.

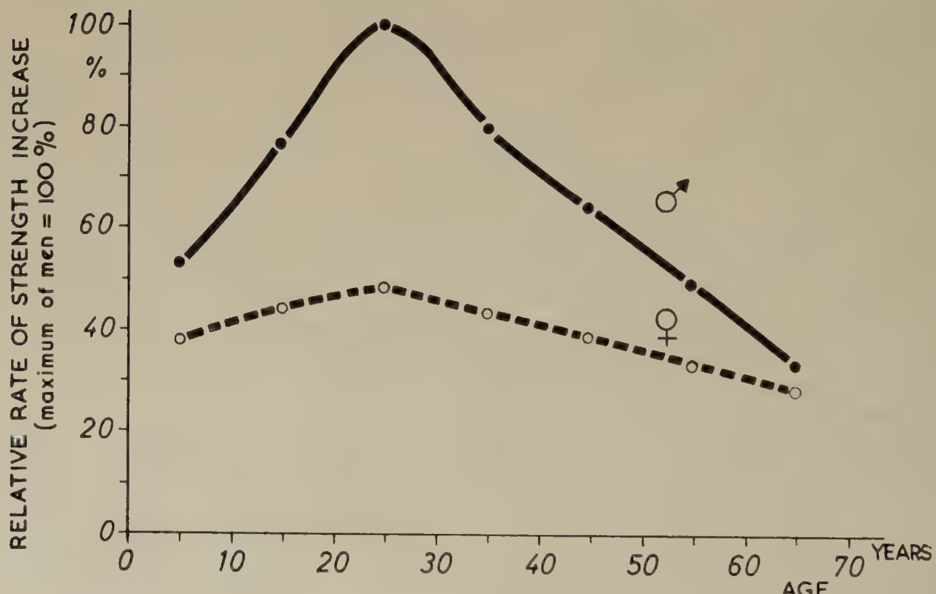


Figure 4. Rates of increase in strength in relation to age for the two sexes.

sexes show a maximum at 25 years, that for women being about 60 per cent that for men. The increase in strength from the 10th to the 25th year for men is about 150 per cent against only 50 per cent for women. This increase is lost by women over the period from the 25th to the 65th year, whereas men retain

about half of the maximum increase, even at the age of 65 years. The course of strength increase of muscle during life gives a different picture therefore for the two sexes.

The results presented in Fig. 3 can be expressed in terms of the rates at which strength increase occurs in the two sexes at different ages. This is shown in Fig. 4.

It is not known whether there is a correlation between the speed of strength-increase and the endpoint up to which increase is possible. A linear increase in strength up to double the initial strength in many experiments was found. In other experiments, however, no further training occurred after a relatively small growth of muscle. More work has to be done on this problem.

Increase of strength through training can be prevented by a low protein intake. On the other hand it is not possible to speed up the growth of muscle mass by feeding on a high protein diet. A better increase was found in August–September compared with January (Hettinger and Müller 1955). This is probably due to the change of ultra-violet radiation in the course of the year (Hettinger and Seidl 1956).

La force musculaire s'adapte aux besoins par moyen de la croissance musculaire. L'incitation à l'accroissement de force musculaire n'est pas la fatigue mais la force exercée pendant la tâche. Quand cette force est à l'excès d'un tiers de la force maximum, le taux maximum de l'accroissement de force est atteint à raison d'une seule contraction statique de courte durée parjour. Avec une seule contraction de courte durée par semaine, le taux est à un tiers de ce maximum. La perte de force après l'entraînement par contraction diurnale a lieu au meme taux que l'accroissement. L'accroissement plus lent par l'entraînement hébdomadaire fait acquérir une force plus permanente. Pour éviter la fatigue dans le travail statique les muscles doivent être entraînés par rapport à une force à peu près le double de la force statique la plus grande qui sera necessaire pendant la tâche.

L'inactivité abaisse la force à peu près par 30 pour cent la semaine; le retour à la force normale une fois l'activité réétablie est également rapide. L'atrophie peut être évitée par moyen d'une contraction par jour avec une force d'un cinquième de la force maximum. La force normale peut être maintenue par des contractions dont la force est située entre un cinquième et un tiers de la force maximum. La capacité des muscles à augmenter la force maximum varie d'un muscle à une autre et d'une personne à une autre. Pour les hommes elle est au maximum à 25 ans et à la moitié du maximum aux âges de 10 et de 60 ans. Le taux d'accroissement chez les hommes est le double de celui des femmes à l'âge de 25 ans et à 25 pour cent plus elevé à 10 et à 60 ans. Cette susceptibilité d'entraînement est au maximum l'été et au minimum l'hiver. Elle réagit positivement à l'exposition à la radiation ultra-violette. Elle n'est pas améliorée par un régime abondant en protéine, mais elle est diminuée par un regime où les protéines sont insuffisantes.

Die Muskelkraft passt sich den Aenderungen einer Tätigkeit durch Muskelwachstum an. Der Reiz für ein Muskeltraining ist nicht die Ermüdung, sondern die Kraft, die während der Tätigkeit ausgeübt wird, wenn sie 1/3 der Maximalkraft übersteigt. Um Ermüdung bei statischer Arbeit zu vermeiden, sollte man den Muskel gegen eine Kraft trainieren, die ungefähr doppelt so hoch ist, wie die höchste statische Kraft, die während der Tätigkeit auftritt. Die grösstmögliche Geschwindigkeit der Zunahme der Muskelkraft wird schon dann erreicht, wenn eine einzige, kurze statische Kontraktion jeden Tag, 1/3 dieser maximalen Geschwindigkeit, wenn eine einzige kurze Kontraktion jede Woche ausgeübt wird. Der grösst-mögliche Kraftgewinn bei täglichem Training (ungefähr 5 prozent je Woche), fällt nach Beendigung des Trainings mit etwa der gleichen Geschwindigkeit, während der langsamere Kraftgewinn bei wöchentlichem Training dazu führt, dass die Kraft für 1 Jahr und länger auf einem höheren Niveau erhalten bleibt. Inaktivität verringert die Kraft um etwa 30 prozent in einer Woche bei gleicher Geschwindigkeit der Rückkehr zur Normalkraft bei neuer Tätigkeit. Mit einer täglichen Kontraktion von wenigstens 1/5 der Maximalkraft lässt sich Atrophie verhindern. Normalkraft ist durch die Muskelkraft definiert, die weder zu- noch abnimmt, wenn man Kontraktionen gegen Kräfte zwischen 1/5 oder 1/3 der Maximalkraft ausübt. Die Trainierbarkeit wechselt von Muskel zu Muskel und von Person zu Person. Für Männer ist sie maximal mit 25 Jahren, halb-maximal mit 10 und 60 Jahren. Die Trainierbarkeit der Männer ist doppelt so gross wie die der Frauen mit

25 Jahren, dagegen 25 prozent höher mit 10 und 60 Jahren. Die Trainierbarkeit hat ein Minimum im Winter, ein Maximum im Sommer. Sie reagiert positiv auf ultraviolette Bestrahlung. Sie wird nicht verbessert durch eine Diät mit viel Eiweiss, dagegen reduziert durch eine zu niedrige Eiweissaufnahme.

References

Barcroft, H., and Swan, H. J. C., 1952, *Sympathetic Control of Human Blood Vessels* (London : E. Arnold & Co.), p. 45.

Hellebrandt, F. A., Parrish, A. M., and Houtz, S. J., 1947, The influence of unilateral exercise on the contra-lateral limb. *Arch. phys. Med.*, **28,** 76–85.

Hettinger, Th., 1953, Muskelkraft und Muskeltraining bei Frauen und Mannern. *Arbeitsphysiologie,* **15,** 201–206 ; 1955 a, Untersuchungen zur Bestimmung der Muskelatrophieschwelle. *Int. Z. angew. Physiol. einschl. Arb. physiol.*, **16,** 52–56 ; 1955 b, Der Einfluss der Muskel durchblutung beim Muskeltraining auf den Trainingserfolg. *Ibid.*, **16,** 95–98 ; 1958, Die Trainierbarkeit menschlicher Muskeln in Abhangikeit vom Alter und Geschlecht. *Ibid.*, **17,** 371–377.

Hettinger, Th., and Müller, E. A., 1953, Muskelleistung und Muskeltraining. *Arbeitsphysiologie,* **15,** 111–126 ; 1955, Die Trainierbarkeit der Muskulatur im jahreszeitlichen Verlauf. *Int. Z. angew. Physiol. einschl. Arb. physiol.*, **16,** 90–94.

Hettinger, Th., and Seidl, E., 1956, Ultraviolettbestrahlung und Trainierbarkeit der Musk ulatur. *Int. Z. angew. Physiol. einschl. Arb. physiol.*, **16,** 177–183.

Müller, E. A., 1957, The regulation of muscular strength. *J. Ass. phys. ment. Rehab.*, **11,** 41–47.

Müller, E. A., and Hettinger, Th., 1953, Ueber Unterschiede der Trainingsgeschwindigkeit atrophierter und normaler Muskeln. *Arbeitsphysiologie,* **15,** 223–230 ; 1594, Die Bedeutung des Trainingsverlaufes für die Trainingsfestigkeit von Muskeln. *Ibid.*, **15,** 452–458 : 1956, Der Vaulauf der Zunahme der Muskelkraft nach einem einmaligen maximalen Trainingsreiz. *Int. Z. angew. Physiol. einschl. Arb. physiol.*, **16,** 184–191.

Siebert, W., 1928, Untersuchungen über Hypertrophie des Skelettmuskels. *Klin. Med.*, **109,** 350–359.

Schochrin, W. A., 1935, Die Muskelkraft der Beuger und Strecker des Unterschenkels. *Arbeitsphysiologie,* **8,** 251–260.

Ufland, J. M., 1934, Einfluss des Lebensalters, Geschlechtes, der Konstitution und des Berufs auf die Kraft verschiedener Muskelgruppen. *Arbeitsphysiologie,* **7,** 232–237.

ABSTRACTS OF OTHER PAPERS DELIVERED AT THE SYMPOSIUM

THE RÔLES OF SENSORY FEEDBACK IN TRAINING AND PERFORMANCE

By J. Annett

Institute of Experimental Psychology, University of Oxford

The design of training devices in accordance with apparently well-known psychological principles does not result in unqualified success. These principles seldom have the generality popularly attributed to them. In the traditional area of ' transfer of training ', for example, the theoretical emphasis has been on the value of similarity between tasks yet exact simulation is often impracticable and possibly important items of feedback, such as, in a flying simulator, the gravitational changes which arise in a real aircraft, are sometimes omitted. On the other hand crude mock-ups are often found to be useful in training. The problem of what is transferred from training on one device to performance on another has not been satisfactorily solved. A further inconsistency of theory with practice is the laboratory finding that transfer is greater from a difficult task to an easy one than vice versa. Yet training devices are often designed to simplify the task and make it initially easier for the trainee. Despite the apparent success of part-whole and isolation methods which include the massing of practice on some items, recent laboratory work has found that continuous practice may lead to slower learning even where the continuity is achieved by trainees simply watching others practising during their own rest pauses.

Whilst some training devices effectively simplify the operation and restrict the sensory feedback arising from it, others give extra feedback in the form of knowledge of results. In the light of recent experiments at Oxford the well-known principles that learning is best where knowledge of results is most immediate, most accurate or informative, and most frequent, must be reconsidered and qualified.

In these experiments subjects had to learn to exert a precise pressure on a rigid metal bar and knowledge of results was supplied either visually or verbally, either immediately or with slight delay, either more or less accurate, and finally either on all or only half of the trials. Whilst subjects with the most immediate, accurate and frequently presented knowledge of results learned quickly, they were very much the worse off when it was subsequently removed. In this case ease and speed of learning on the training device was negatively correlated with success on the actual task.

Theoretical problems about the interaction of one type of feedback data with another and the relation of different kinds and amounts of feedback to the acquisition of skill point the need for further research.

(The data of these experiments will be published shortly in the *Quarterly Journal of Experimental Psychology* under the title " Learning a pressure under conditions of immediate and delayed knowledge of results ".)

EFFECTS OF NOISE EARLY IN TRAINING UPON SUBSEQUENT PERFORMANCE

By D. E. Broadbent

Applied Psychology Research Unit, Cambridge, England

Three groups of naval ratings worked for two sessions each at a subtraction task involving a considerable immediate memory load. One group had both sessions in relative quiet (70 db), a second had the first session in 100 db noise and the second in quiet, and the third group had noise and quiet in the reverse order.

In the first session the noise group slowed down at solving the subtractions as time went on, relative to the groups working in quiet. A similar difference appeared in the second session, but, in addition, there was an aftereffect of noise such that the subjects who had had noise previously slowed down relative to those who had not.

Slowing down of performance with time was in all groups most marked in extroverts.

These results suggest firstly that intellectual work as well as simple sensory tasks must be regarded as endangered by noise. Secondly, there may be harmful aftereffects from noise, but it is not clear whether these will appear in any situation or only in one similar to that in which the noise was experienced.

(This paper has been published under the title 'Effect of noise on an intellectual task' in *J. acoust. Soc. Amer.*, 1958, **30**, 824–827.)

THE EFFECTS OF DIFFERENT GRADES OF SHORT-TERM EXERCISE ON THE PHYSICAL FITNESS OF SOME YOUNG MEN

By J. V. G. A. Durnin
Institute of Physiology, University of Glasgow

Many classical studies have been made of the effects of training on physical fitness in humans. These experiments have almost always involved long periods of physical training lasting several weeks or months, and often the exercises have been severe. However, there is very little information on the effect of a short period of exercise, lasting some days, on the physical fitness of relatively untrained young subjects.

In the present series of experiments, an attempt was made to determine whether there were any measurable changes in some cardio-respiratory measurements of healthy but untrained young men, as a result of short-term exercise. The exercise lasted for 10 days and was of different grades of severity. There were four groups of men, the total number of subjects being 44. One group did almost no exercise at all, the second group walked 6 miles per day, the third group 12 miles per day and the fourth group 18 miles per day. Measurements were made of cardio-respiratory function during a standard exercise on the treadmill. These measurements were done before the beginning of the training period, at the end of 5 days of exercise, and again at the end of the 10 days.

HABITABILITY REQUIREMENTS FOR LONG DURATION MISSIONS

By Dean Farnsworth
U.S. Office of Naval Research, London

Long duration missions in confined quarters in which personnel monitor mechanized equipment have greatly changed the physiological and psychological environment of many military and civilian operations. The type of people who best respond to advanced technical training are least receptive to a continuously emotionally austere way of living. This paper summarized a ten-year programme of study and experiment at the U.S. Naval Submarine Base, New London, Connecticut, in connection with such units as submarines, airships and isolated observer stations. Successes and failures were described which led to the principles of the present 'Habitability Programme' aimed at holding trained personnel and increasing their efficiency.

MAXIMAL WORK PRODUCTION IN MAN

By J. G. Fletcher
Division of Human Physiology, National Institute for Medical Research, London

The maximal amount of physical work which a man can do depends partly on his skill and motivation, but principally on how much chemical energy he can transform to mechanical energy in his muscles. Evidence was recently obtained (Fletcher 1958) that well-motivated young men were able to increase their maximal output very rapidly by exercising once per day to exhaustion, using a constant high rate of work. This communication reviews that evidence, and describes further experiments in which accompanying physiological changes were investigated and rates of improvement were compared in different subjects.

Ten healthy men aged 20–46 took part. All were interested in measuring their capacity for exercise; three exercised once only and seven exercised repeatedly. One simple work test (stepping up and down on a 20 in. bench at a rate of 30 cycles per minute for as long as possible) was used so that acquisition of skill should play no great part in any improvement. The duration of each experiment was recorded and the heart rate and number of breaths per minute were counted before and after stepping.

The results showed that:

(*a*) At first unfit men could step only for 0–1½ min, fit men achieved 1½–10 min, and a cross-country runner 35 min.

(*b*) Endurance improved rapidly with repetition. The athletes achieved 30 min of stepping without difficulty and three non-athletes achieved 15 min.

(*c*) The rate of improvement was greater in athletes than in non-athletes and was least in relatively unfit subjects.

(*d*) The resting heart rate was lower after training than before training, and recovery after work was more rapid.

(*e*) Subjects who were re-tested after periods without training all retained some improvement.

It was concluded that in this type of exercise maximal output can be increased markedly if subjects are prepared to work to exhaustion.

Reference

Fletcher, J. G., 1958, Adaptation in man to exhausting physical work. *J. Physiol.*, **141**, 35–36.

THE PROBLEM OF MANAGEMENT DEVELOPMENT IN INDUSTRY SOME MUSINGS WITHOUT MUCH METHOD

By F. I. de la P. Garforth
Engineering and Allied Employers' West of England Association, Bristol

'Management Development' or 'Executive Development' has in recent years become a fashionable cry amongst personnel people in the U.S.A. and later in the U.K. It has been described by Anne Shaw as meaning:

"Systematic plans for selecting, improving and promoting each individual member of the management team to get the best from everyone and to ensure the succession to key jobs."

In some cases this is seen as referring to the whole hierarchy from production chargehand or office section leader up to managing director level, while more commonly it is regarded as applying only to providing for future needs at top and senior levels. In either case the problem embraces recruitment, selection and placement; individual education, training and development; collective training and development; and periodic re-appraisal of the potential capacity and ceiling of individuals as leaders and administrators.

The importance of early recognition and full development of managerial talent can hardly be questioned. What can be questioned is the validity and reliability of the various attempts being made to achieve these aims. It is, of course, hardly surprising that there is an almost complete absence of satisfactory objective evidence or controlled experiment in this field.

A few of the many questions, general and detailed, which spring from any serious attempt to deal with the problem are:

(*a*) Is it possible to arrive at a limited number of valid concepts which can be satisfactorily used by practical and practising managers in appraisal of potential managerial capacity, e.g. general intelligence level, education, experience, motivation, adjustment and mental and physical energy.

(*b*) Where does the balance of advantage lie in any given circumstances between the 'Rugged Individualist' and Mr. William H. Whyte's 'The Organisation Man'? Or alternatively what are the advantages and disadvantages of 'directive' or 'autocratic' and of 'democratic' or 'permissive' leadership?

(*c*) Are the 'Personality' tests which flourish in some quarters in America worth the paper they are printed on?

(*d*) In appraisal is it more reliable to assess against defined 'standards' or against a mental concept of 'average for his age and level'?

(*e*) Are 'overall' judgments likely to be more reliable than the results of some system of differentiated merit ratings—or is the latter a necessary preliminary to the former?

(*f*) Can the mediocre manager be expected to recognise exceptional potential in any of his younger subordinates? Can the lesser comprehend the greater?

(*g*) Is it true that 'there will be demands—for any kind of procedure which will evade the conclusion that in the successful organisation of executive tasks there must be leaders and that, in every generation, only an infinitesimal minority of the whole will be fitted for tasks of top leadership' (Urwick)? And, if so, what is this leadership?

(*h*) At the present state of our knowledge are all attempts at a systematic approach likely to be worse than useless ?

These are deplorably woolly and intractable questions. Much has been and is being learnt about human performance in the area of operative skills and physical effort. Is it reasonable to expect—perhaps 'hope' would be the wrong word—that equivalent advances may be made in the next twenty-five years in the field of managerial capacities and performance.

THE EFFECT OF FATIGUE ON TRAINING

By O. Graf
Max-Planck-Institut fur Arbeitsphysiologie, Dortmund

Two experiments were reported in which four female workers took part comparing spaced with continuous practice. Spaced practice over a period of fourteen days resulted in surer movements and faster work than did continuous practice spread over four months. The types of work studied were punching, bradawling and rivetting. A cinematograph analysis of movements was made. The results of the study are interpreted in terms of the influence of fatigue in continuous practice which results in the development and retention of incorrect movements and in decreased success of the operator's performance.

TRAINING: AN EXPERIMENTAL INVESTIGATION

By A. Lundervold
The Neurological Clinic, Department of Neurophysiology, University of Oslo, Norway

The material presented in this paper has been published under the title 'Electromyographic investigations during typewriting' in *Ergonomics*, 1958, **1**, 226–233.

SPECIALIZED OPERATIVE TRAINING IN THE LANCASHIRE TEXTILE INDUSTRY

By W. E. Sutcliffe
Cotton Board Productivity Centre, Manchester

Cotton textiles is a widely diversified industry of many small, a fair proportion of medium sized and very few large producing units. Management methods must cater for all systems of production ranging from mass production to almost wholly jobbing work. In certain sections there is a predominance of repetitive manual work and operatives mind hundreds, even thousands of production heads, whilst in others the work is performed on single, specially designed machines.

In addition to this, a large proportion of the labour force is of high average age and due to re-equipment and modernization, much of this labour requires conversion training, or re-training for new jobs. Recruitment of juveniles is often difficult owing to lack of confidence in the industry

The industry has time and again been in the forefront in the use of up-to-date management techniques and the Cotton Board, as central representative body for the entire industry, made available to it the system of training known as Specialized Operative Training some four years ago.

On a three-week course, training officers are taught how to apply specialized operative training. These people return to their companies and set up this system of training under the guidance of experienced Cotton Board tutors. Alternatively, the system is applied by Cotton Board staff on a consultative basis.

Training in the larger companies is dealt with by training officers and their staff. In the smaller units a carefully selected instructress usually suffices, so long as training is directed by a senior executive.

Some fifty schools are now in existence and the results achieved in these are becoming widely known within the industry and are stimulating interest at a rapidly increasing rate. Briefly the results so far achieved are:—

1. Training times are reduced by up to 75 per cent with a marked decrease in the true cost of training.
2. The standard of performance of operatives trained by this method is equal to, or better than, the average of experienced operatives, both with regard to quantity and quality.
3. Recruitment has been brought to a much more satisfactory level and the post-training turnover minimized.
4. Faulty work produced by trainees is reduced and is separate from normal production.
5. Management has control of, and can measure the progress of trainees, thus enabling more concrete policies to be set.
6. All levels, management, operatives and their Trade Unions, back it in a positive, active manner.

TRAINING PROBLEMS IN THE FIELD OF PERCEPTUAL SKILLS

By D. Wallis

Department of the Senior Psychologist, Admiralty, London

There are some operating tasks where the motor elements are so simple or infrequent as to be relatively unimportant, whereas success is critically dependent upon continuous perceptual activity. Examples are the detection and classification of sonar and radar contacts, i.e. of underwater, surface and airborne targets. In these cases it is legitimate to label the skills involved as ' perceptual '.

Little is known about how to train operators in these perceptual skills. Training devices and methods are in widespread use, however, without much evidence of their effectiveness. Some of the problems encountered in trying to improve Naval sonar and radar training were discussed, with the rationale behind methods actually adopted. It is argued that the approach to perceptual training problems must be analytic in the first place, through a breakdown of the perceptual skills involved. Training itself then consists of:

(*a*) Demonstrating the significant perceptual clues among data displayed throughout the task.

(*b*) Providing realistic practice at the task, with knowledge of performance.

Some theoretical and practical issues were discussed arising from this empirical approach to perceptual training.

The paper by F. H. Bonjer entitled ' The effects of aptitude, fitness, physical working capacity, skill and motivation on the amount and quality of work ', will be published in full in the next issue.

Attention is also called to the following papers already published in this Journal :

Belbin, E., 1958, Methods of training older workers. *Ergonomics*, **1**, 207–221.

Belbin, E., Belbin, R. M., and Hill, F., 1957, A comparison between the results of three different methods of operator training. *Ergonomics*, **1**, 39–50.

Dale, H. C. A., 1958, Fault-finding in electronic equipment. *Ergonomics*, **1**, 356–385.

de Jong, J. R., 1957, The effects of increasing skill on cycle time and its consequences for time standards. *Ergonomics*, **1**, 51–60.

ERGONOMICS RESEARCH SOCIETY ANNUAL CONFERENCE: April 6th–9th

The Society's Annual Conference will be held this year at Balliol College, Oxford, on

ERGONOMICS : ITS PLACE IN INDUSTRY

(Past progress and future trends)

Among topics to be discussed will be the application of ergonomics research to working conditions, measurement of performance, industrial skills, and human efficiency generally. Highlights of research during the last ten years will be reviewed, with accounts of recent applied studies in industry. There will also be papers dealing with anticipated industrial needs and trends in ergonomics research.

The Society will welcome visitors to the Conference. Applications for places, or for further details of the arrangements, should be sent to :—

The Honorary Treasurer and Membership Secretary,
Ergonomics Research Society,
Department of Psychology,
University of Bristol,
22, Berkeley Square,
BRISTOL, 8.

INSTRUCTIONS TO CONTRIBUTORS

1. Articles for publication should be sent to the General Editor or to any Member of the Editorial Board.

2. Papers must be in English, French or German. Every paper must be accompanied by a brief summary, and contributors are asked if possible to supply summaries in all three languages.

3. Articles must be concise and should not normally exceed 6000 words.

4. Authors should submit a typescript, double-spaced on one side of the paper only. Footnotes should be avoided. Summaries, tables and legends for diagrams should be typed on separate sheets. Authors must ensure that the lay-out of mathematical and other formulae is clear. The typescript must represent the final form in which the author wishes the article to appear. The cost of any alteration in proof other than printers' errors may be charged to the author.

5. Diagrams should be drawn in black ink on white card or tracing paper. They should normally be sufficiently large to allow reduction in printing and the lines should therefore be bold. **All lettering should be up to draughtsmanship standard, suitably drawn in Indian ink to allow for reduction in size.** No charges are made for reproducing tables, diagrams or half-tone illustrations, but diagrams not suitable for reproduction without redrawing may be redrawn at the Author's expense.

6. References in the text should be indicated by author's name followed by the date. They should be listed alphabetically at the end of the paper in the style illustrated by the following examples:

BARTLETT, F. C., 1943, Fatigue following highly skilled work. *Proc. roy. Soc.* B, **131**, 247–254.

BEDFORD, T., 1948, *Basic Principles of Ventilation and Heating* (London: H. K. Lewis).

LE GROS CLARK, W. E., 1954, The anatomy of work. In *Symposium on Human Factors in Equipment Design* (Edited by W. F. Floyd and A. T. Welford) (London: H. K. Lewis). Pp. 5–15.

Abbreviations should be as in the *World List of Scientific Periodicals.*

7. **Consideration for publication will gladly be given to papers which have previously had a limited circulation as research reports.** Submission of a paper implies, however, that it has not been published and will not be published elsewhere without the permission of the General Editor and the Publishers. Copyright in material accepted for publication is retained by the Journal, and reproduction in whole or in part is forbidden except under the terms of the *Fair Copying Declaration* of the Royal Society or with the written permission of the Publishers.

8. Authors will receive 25 copies of their contributions without charge. Additional copies may be ordered at the time of returning proofs. Prices for additional copies may be obtained from the Publishers.

ERGONOMICS

Volume 2 February 1959 Number 2

Contents

Symposium on Training